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OHIO UNIV ATHENS DEPT OF ELECTRICAL ENGINEERING

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EFFECTS OF HIGH VOLTAGE TRANSMISSION LINES ON NON-DIRECTIONAL B--ETC(U)

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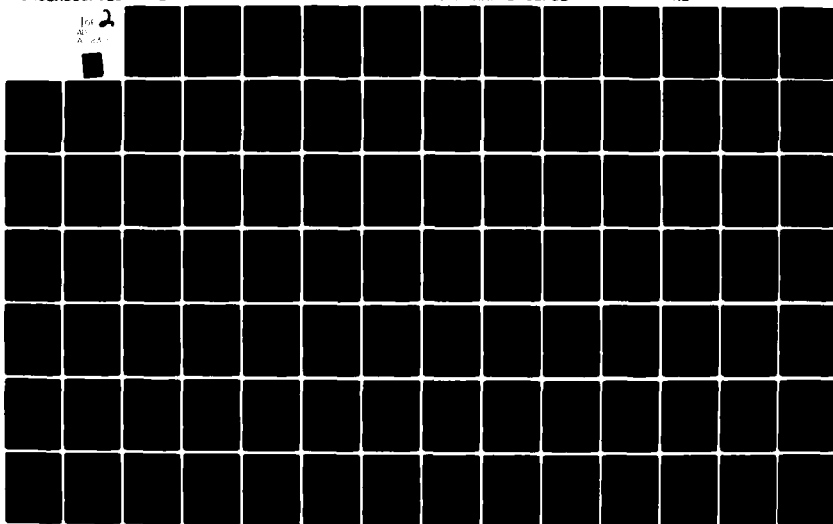
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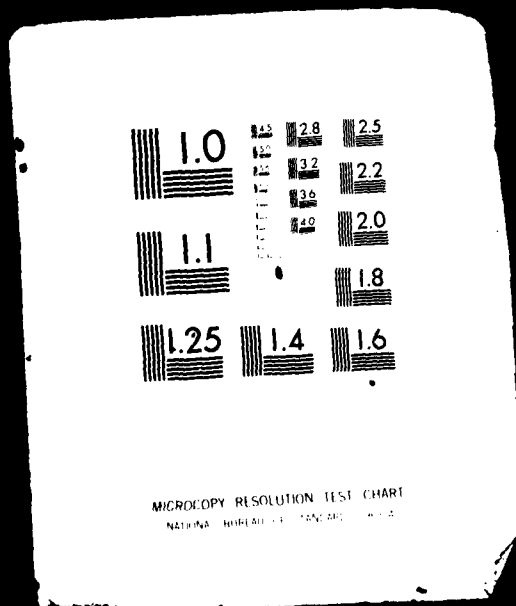
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Effects Of High Voltage Transmission Lines On Non-Directional Beacon Performance

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16. Abstract The potential for high-voltage transmission lines to interfere with the operation of non-directional beacons through the mechanisms of coronagenerated radio noise or passive reradiation of the desired signal has been assessed by use of computer prediction models. The generated noise levels were calculated for both AC and DC lines using methods found in the appropriate literature which have previously been compared with measured data. The reradiated signal levels were computed using a moment-method wire model computer program. This approach was validated by measurements made by the authors and reported herein. For all situations considered, it was concluded that locating an NDB near a high-voltage transmission line should not impair the function of the NDB due to either corona noise or passive reradiation from the line.			
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ENGLISH/METRIC CONVERSION FACTORS

LENGTH

To From	Cm	m	Km	in	ft	S mi	n mi
Cm	1	0.01	1×10^{-5}	0.3937	0.0328	6.21×10^6	5.39×10^6
m	100	1	0.001	39.37	3.281	0.0006	0.0005
Km	100,000	1000	1	39370	3281	0.6214	0.5395
in	2.540	0.0254	2.54×10^{-5}	1	0.0833	1.58×10^{-5}	1.37×10^{-5}
ft	30.48	0.3048	3.05×10^{-4}	12	1	1.89×10^{-4}	1.64×10^{-4}
S mi	160,900	1609	1.609	63360	5280	1	0.8688
n mi	185,200	1852	1.852	72930	6076	1.151	1

AREA

To From	Cm ²	M ²	Km ²	in ²	ft ²	S mi ²	n mi ²
Cm ²	1	0.0001	1×10^{-10}	0.1550	0.0011	3.86×10^{11}	5.11×10^{11}
m ²	10,000	1	1×10^{-6}	1550	10.76	3.86×10^7	5.11×10^7
Km ²	1×10^{10}	1×10^6	1	1.55×10^9	1.08×10^7	0.3861	0.2914
in ²	6.452	0.0006	6.45×10^{-10}	1	0.0069	2.49×10^{-10}	1.88×10^{-10}
ft ²	929.0	0.0929	9.29×10^{-8}	144	1	3.59×10^{-8}	2.71×10^{-8}
S mi ²	2.59×10^{10}	2.59×10^6	2.590	4.01×10^9	2.79×10^7	1	0.7548
n mi ²	3.43×10^{10}	3.43×10^6	3.432	5.31×10^9	3.70×10^7	1.325	1

VOLUME

To From	Cm ³	Liter	m ³	in ³	ft ³	yd ³	fl oz	fl pt	fl qt	gal
Cm ³	1	0.001	1×10^{-6}	0.0610	3.53×10^{-5}	1.31×10^{-6}	0.0338	0.0021	0.0010	0.0002
Liter	1000	1	0.001	61.02	0.0353	0.0013	33.81	2.113	1.057	0.2642
m ³	1×10^6	1000	1	61,000	35.31	1.308	33,800	2113	1057	264.2
in ³	16.39	0.0163	1.64×10^{-5}	1	0.0006	2.14×10^{-5}	0.5541	0.0346	0.0173	0.0043
ft ³	28,300	28.32	0.0283	1728	1	0.0370	957.5	59.84	0.0173	7.481
yd ³	765,000	764.5	0.7646	46700	27	1	2590	160.5	607.9	202.0
fl oz	29.57	0.2957	2.96×10^{-5}	1.805	0.0010	3.87×10^{-5}	1	0.5825	0.0312	0.0078
fl pt	473.2	0.4732	0.0005	28.88	0.0167	0.0006	16	1	0.5000	0.1250
fl qt	948.4	0.9463	0.0009	57.75	0.0334	0.0012	32	2	1	0.2500
gal	3785	3.785	0.0038	231.0	0.1337	0.0050	128	8	4	1

MASS

To From	g	Kg	oz	lb	ton
g	1	0.001	0.0353	0.0022	1.10×10^{-6}
Kg	1000	1	35.27	2.205	0.0011
oz	28.35	0.0283	1	0.0625	3.12×10^{-5}
lb	453.6	0.4536	16	1	0.0005
ton	907,000	907.2	32,000	2000	1

TEMPERATURE

$$^{\circ}F = 9/5 (^{\circ}C - 32)$$

$$^{\circ}C = 5/9 (^{\circ}F) + 32$$

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This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.
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Chapter I

INTRODUCTION

1.1 Introduction

The purpose of this report is to provide an engineering basis for predicting the effects of nearby power transmission lines on the performance of Non-Directional Beacons. Two basic mechanisms for possible interference have been considered; Radio Frequency noise generated by the lines themselves, and passive reradiation of the NDB signal by the transmission line towers and conductors. Since the production of radio noise is very different for AC and DC lines, a separate chapter is devoted to each. A third chapter is devoted to reradiation effects (both AC and DC lines will behave similarly). The conclusions reached are discussed in a final chapter; however, the fundamental conclusion is that locating the NDB transmitter near a power transmission line should not have any detrimental effects due to the above mechanisms. It must be immediately pointed out, however, that other mechanisms, such as powerline carrier radiation, are not included in the above statement.

In this report the signal from the NDB transmitter is the desired signal, and the RF noise from the powerlines or the reradiated signal from the powerline structures the undesired. The FAA Handbook¹ states that if the level of the undesired signal is 15 dB below that of the desired signal, the ADF positioning error will be less than ± 1 degree. This criteria will be applied throughout this work for assessing the potential of interference.

The objective of this report is to provide a theoretical capability to predict the critical distance between the powerlines and receiving aircraft where the ratio of the desired signal/undesired noise is 15 dB as a function of effective radiated power of the NDB transmitter, relative permittivity and ground conductivity of the earth, powerline parameters, distance separating the NDB transmitter and the powerline, evaluation of the ADF receiver and the NDB frequency. This objective has been successfully met. In particular, mathematical models now exist which will provide the desired predictions.

Chapter II

PREDICTION OF RADIO INTERFERENCE NOISE FROM AC POWERLINES

2.1 Introduction

Radio Interference (RI) noise from AC powerlines originates from corona, which is defined as "a luminous discharge due to ionization of the air surrounding a conductor around which exists a voltage gradient exceeding a certain critical value".² An IEEE Report³ states that the RI performance can be divided into three stages: 1) generation, 2) propagation and 3) radiation.

The generation of corona, and therefore RI, is basically a function of factors which can be divided into two categories: i) line design factors and ii) atmospheric and environmental factors. The former includes the diameter and spacing of conductors, phase spacing and phase configuration. The latter deals with the accumulation of foreign particles on the line conductors and weather conditions.

The propagation of RI along the powerlines is primarily a function of the line design and earth resistivity, both of which influence the rate of attenuation of the traveling waves. The radiation of RI away from the powerlines is essentially dependent on the positions of the phases of the lines with respect to the location of the observer.

Studies and reports^{2,3,4} have consistently concluded that the RI noise level is at its peak under heavy rain condition. All predictions of RI noise from AC powerlines given in this report will be for the worst case condition of a heavy rain shower.

2.2 Computation of RI Noise from AC Powerlines

CIGRE/IEEE Survey Results⁴ list various methods for the calculation of RI noise from AC powerlines. They are grouped into two categories: i) the comparative method and ii) the analytical method. The former makes use of an empirical formula developed after a careful measurement study with particular reference criteria. To predict the RI noise level from lines of different designs, various corrections for corona generation, measurement frequency and lateral distance are made based on measurements of the variables involved. The analytical method, on the other hand, makes use of a theoretical characteristic quantity of RI generation which is called the excitation function, and proceeds to compute the total corona currents on the lines and the resulting RI noise field strength at the location of the observer.

The method that will be used here belongs to the latter group and is called the "modal analysis method".⁵ It assumes that the powerlines are a reflection-free system of n ideally parallel conductors at constant height above a perfectly flat conducting ground whose potential is zero. The influence of the ground wires is included in determining the surface gradients, but is neglected for the modal currents. The method is composed essentially of the following steps:

Step 1. Determination of the maximum bundle surface gradient

The maximum bundle surface gradient for each phase can be determined by using a method developed by Markt and Mangele⁶. The calculation is carried out with the assumption that:

- the ground is an infinite horizontal conducting plane surface,
- the conductors are smooth infinitely long circular cylinders parallel to each other and to the ground plane,

- the conductors are equipotential surfaces, with known potentials applied to them, the ground plane is assumed to be at zero potential,
- the influence of powerline towers and of any objects in the vicinity is neglected and
- the horizontal spacing between the conductors remains constant and the height of the conductors above ground is also constant.

The procedures for the calculation of the maximum bundle surface gradient are detailed below:

Step a: Each conductor bundle is replaced by an equivalent conductor having a radius r_{eq} defined by

$$r_{eq} = (n a A^{n-1})^{1/n} \quad (2-1)$$

where: n is the number of subconductors,

a is the subconductor radius,

A is the bundle radius.

Step b: With the bundles represented by the equivalent conductors, the total charge on each of them is calculated by the Maxwell potential coefficient method assuming appropriate potentials on the different phases. Any ground wires are also taken into account. Program CHARGE listed in Appendix B is used to compute the values of the total charge q_t on the bundles.

Step c: The average bundle gradient is calculated as:

$$E_{av} = \frac{q_t}{2\pi\epsilon_0} \cdot \frac{1}{n a} \quad (2-2)$$

Step d: Finally the maximum bundle surface gradient is obtained as:

$$E_m = E_{av} (1 + (n-1) \frac{a}{A}) \quad (2-3)$$

Step 2. Determination of RI excitation function under heavy rain conditions

The excitation function is considered to be the specific measure of the cause of RI. It is related to the induced corona currents by the equation⁷

$$i = \frac{C}{2\pi\epsilon_0} \cdot \Gamma \quad (2-4)$$

where: i is the induced corona current injected per unit length of the conductor,

C is the capacitance of the conductor

ϵ_0 is the permittivity of air,

Γ is the excitation function.

In this analysis, an empirical formula developed by EPRI⁸ will be used. For each phase, the value of excitation function Γ is given by:

$$\Gamma(n,d) = 78.0 - \frac{580.0}{E_m} + 38.0 \log \left(\frac{d}{3.8} \right) + K_n \quad (2-5)$$

where $\Gamma(n,d)$ is the excitation function for a bundle of n subconductors of diameter d (cm) in units of dB above $1 \mu A/m^{1/2}$,

$$K_n = 7 \text{ dB, if } n = 1,$$

$$K_n = 2 \text{ dB, if } n = 2,$$

$$K_n = 0 \text{ dB, if } n \geq 3.$$

Step 3. Determination of the geometric matrix [G] of the powerlines

From the powerline configuration, the elements of the geometric matrix [G] can be calculated with the equations⁸

$$g_{ii} = \ln \frac{2h_i}{r_i} \quad (2-6)$$

$$g_{ij} = \ln \frac{D_{ij}}{d_{ij}} \quad (2-7)$$

where: h_i is the height above ground of the i th conductor,
 r_i is the radius of the i th bundle conductor,
 D_{ij} is the distance between the i th conductor and the image of
the j th conductor in the ground plane,
 d_{ij} is the distance between the i th and j th conductors.

Step 4. Determination of the modal transformation matrix [M]

The RI propagation along the powerlines, including the corona generated current along the conductors, can be written by the equations⁵

$$\frac{d}{dx} [V] = - [z] [I] \quad (2-8)$$

$$\frac{d}{dx} [I] = - [y] [V] + [J] \quad (2-9)$$

where: $[V]$ is the column vector of voltage on the line,
 $[I]$ is the column vector of current on the line,
 $[J]$ is the corona current density injected on the conductor,
 $[z]$ is the square matrix of series impedance per unit length of
the line,
 $[y]$ is the square matrix of the shunt admittances per unit length
of the line.

Modal analysis is used to simplify the equations (2-8) and (2-9) above into a number of uncoupled sets of equations which can be solved conveniently. At this stage, it is assumed that the line is lossless. The lossless line parameters are given by

$$[z] = \omega [L] = \omega \frac{\mu_0}{2\pi} [G] \quad (2-10)$$

$$[y] = \omega [C] = \omega 2\pi\epsilon_0 [G]^{-1} \quad (2-11)$$

where: $[L]$ is the inductance matrix of the line,
 $[C]$ is the capacitance matrix of the line,

μ_o is the permeability of air,

ϵ_o is the permittivity of air.

Equation (2-4) in Step 2 can be rewritten as

$$[J] = \frac{1}{2\pi\epsilon_o} [C][\Gamma] = [G]^{-1}[\Gamma] \quad (2-12)$$

Substituting equations (2-10) to (2-12) into equations (2-8) and (2-9) yield

$$\frac{d}{dx} [V] = - \frac{\omega\mu_o}{2\pi} [G][I] \quad (2-13)$$

$$\frac{d}{dx} [I] = - \omega 2\pi\epsilon_o [G]^{-1}[V] + [G]^{-1}[\Gamma] \quad (2-14)$$

Let the modal matrix of $[G]$ be $[M]$ and $[\lambda]_d$ be the diagonal spectral matrix of $[G]$, then

$$[M]^{-1}[G][M] = [\lambda]_d \quad (2-15)$$

or

$$[G][M] = [\lambda]_d[M] \quad (2-16)$$

or

$$\{[G] - [\lambda]_d\}[M] = 0 \quad (2-17)$$

The equation (2-17) above has a non-trivial solutions only if the determinant of $\{[G] - [\lambda]_d\}$ is zero. Solving this characteristic equation of $[G]$ yields the eigenvalues λ_1 , λ_2 and λ_3 . Substituting these back into equation (2-17) will yield corresponding eigenvectors. Normalized column eigenvectors will form the modal transformation matrix $[M]$.

Step 5. Determination of modal components of corona current densities in the conductors

Let:

$$[V] = [M][V_c] \quad (2-18)$$

$$[I] = [M][I_c] \quad (2-19)$$

$$[J] = [M][J_c] \quad (2-20)$$

$$[\Gamma] = [M][\Gamma_c] \quad (2-21)$$

where V_c , I_c and J_c are the modal components of the voltage and currents and Γ_c is the modal components of the RI excitation function. Substituting equations (2-18) to (2-21) into equations (2-13) and (2-14) yield

$$\frac{d}{dx} [M][V_c] = - \frac{\omega \mu_0}{2} [G][M][I_c] \quad (2-22)$$

$$\frac{d}{dx} [M][I_c] = - \omega 2\pi \epsilon_0 [G]^{-1} [M][V_c] + [G]^{-1} [M][\Gamma_c] \quad (2-23)$$

Since RI is a direct result of the induced corona currents in the conductors, only the second part of equation (2-23) will be a matter of interest. The modal components of induced corona currents J_c are therefore obtained by the relationship

$$[J_c] = [M]^{-1} [G]^{-1} [M][\Gamma_c] \quad (2-24)$$

or

$$[J_c] = [M]^{-1} [G]^{-1} [\Gamma] \quad (2-25)$$

With the known values of the elements of matrices $[M]$ and $[G]$ and the excitation function for each phase, the values of the modal components of corona currents for each phase can be determined.

Step 6. Determination of corresponding modal components of the currents in the conductors

At this point, the effect of losses will be introduced in the form of modal attenuation factor α which is a function of frequency and ground resistivity. Required values of the attenuation factor can be obtained by using the empirical equation⁸

$$\alpha^m(f, \rho) = (f^{0.8} \sqrt{\frac{\rho}{100}}) \alpha^m(1.0, 100) \quad (2-26)$$

where: m is the mode number,

f is the frequency in Megahertz,

ρ is the ground resistivity in Ohm m

From the EPRI Reference Book⁸, the values of $\alpha^m(1.0, 100)$ are reproduced in Table 2.1 shown below.

Voltage class (kV)	Attenuation Constants		
	$\alpha^1 (m^{-1})$	$\alpha^2 (m^{-1})$	$\alpha^3 (m^{-1})$
362	8.0×10^{-6}	60.0×10^{-6}	350.0×10^{-6}
550	9.3×10^{-6}	70.0×10^{-6}	350.0×10^{-6}
800	10.0×10^{-6}	70.0×10^{-6}	350.0×10^{-6}
1200	10.6×10^{-6}	84.0×10^{-6}	350.0×10^{-6}
1500	10.6×10^{-6}	84.0×10^{-6}	350.0×10^{-6}

Table 2.1 Modal attenuation constants for AC powerlines at 1 MHz with ground resistivity being 100 Ohm-m.

Under heavy rain conditions, the value of ρ is assumed to be 75.00 Ohm-m. Values of the modal components of the currents in the conductors are determined by the equation⁵

$$[I_c^m] = \frac{J_c^m}{2 \sqrt{\alpha^m}} \quad (2-27)$$

Step 7. Determination of the corresponding phase currents

Referring to equation (2-19) in Step 5, it can be rewritten as

$$[I] = [M][I_c^m] \quad (2-28)$$

or it can be expanded to become

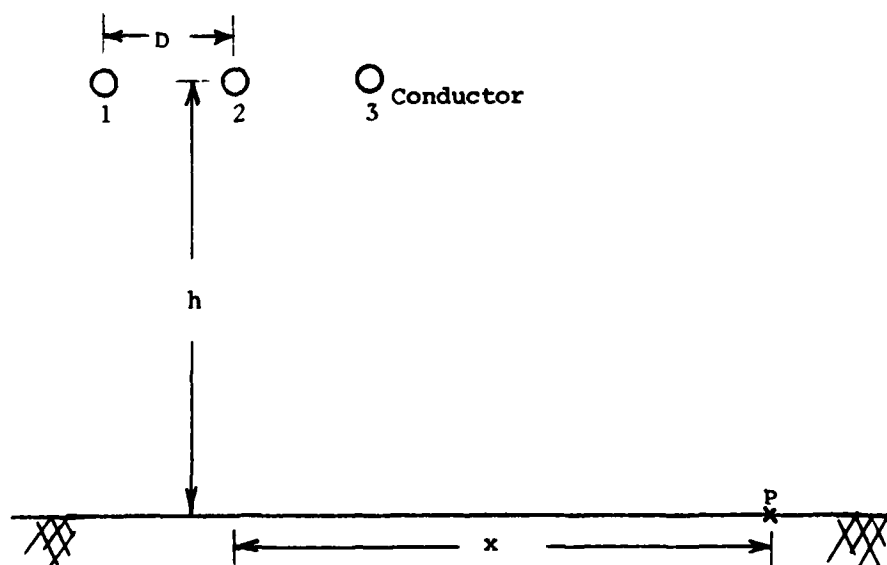


Fig. 2.1 Position of the observer at point P with respect to the AC powerlines for the calculation of RI noise.

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix} \begin{bmatrix} I_c^1 \\ I_c^2 \\ I_c^3 \end{bmatrix} \quad (2.29)$$

Equation (2-29) indicates that each modal current component I_c^m flows in all the three phases. For example, modal current I_c^2 will result current $M_{12}I_c^2$ flowing in conductor 1, $M_{22}I_c^2$ in conductor 2 and $M_{32}I_c^2$ in conductor 3. The current components in the three conductors of any given mode are in phase with each other. However, the currents corresponding to different modes are not in phase due to different velocities of propagation.

Step 8. Determination of the RI noise field strength with the location of the observer at ground level

With the known values of the corona currents in each phase computed above, the resulting magnetic field and electric field can be conveniently calculated. Let the position of the observer be at P as illustrated in Fig. 2.1. The magnetic field strength at this location with respect to the center phase will be

$$H = \frac{I}{2\pi} \cdot \frac{2h}{h^2 + x^2} \quad (2-30)$$

Assuming a TEM mode of wave propagation, the corresponding electric field strength is obtained by the relationship of $E = Z_0 H$, where Z_0 is the wave impedance of free space. Since $Z_0 = 120\pi$, the electric field strength then is

$$E = 60 \cdot I \cdot \frac{2h}{h^2 + x^2} \quad (2-31)$$

where $60 \cdot \frac{2h}{h^2 + x^2}$ is termed as the field factor.

Let the field factors for conductors 1, 2 and 3 be $F_1(x)$, $F_2(x)$ and $F_3(x)$ respectively. Referring to Fig. 2.1 and equation (2-31), the field factors for respective conductors will be

$$F_1(x) = \frac{120h}{h^2 + (x+D)^2} \quad (2-32)$$

$$F_2(x) = \frac{120h}{h^2 + x^2} \quad (2-33)$$

$$F_3(x) = \frac{120h}{h^2 + (x-D)^2} \quad (2-34)$$

Using the above equations (2-32) to (2-34), the electric field strength at any point P due to corona for each mode can be obtained by

$$E_m = F_1(x) \cdot I_1^m + F_2(x) \cdot I_2^m + F_3(x) \cdot I_3^m \quad (2-35)$$

where m is the mode number 1, 2 or 3. The total electric field strength for each phase is calculated from

$$E_{ph} = \sqrt{E_{m=1}^2 + E_{m=2}^2 + E_{m=3}^2} \quad (2-36)$$

Finally, the resultant electric field strength, therefore RI noise, due to corona currents on all the phases at any point P is

$$E = \sqrt{E_{ph=1}^2 + E_{ph=2}^2 + E_{ph=3}^2} \quad (2-37)$$

where E is in $\mu V/m$, or it can be converted into dB above 1 $\mu V/m$.

Appendix A outlines the derivation for equations of field factors for point P anywhere in space and Appendix C details the Program ACRI listings for the computation of RI noise level from AC powerlines.

The RI noise level computed here is for 1 kHz receiver bandwidth.

In general, a bandwidth correction factor of $10 \log b(\text{dB})$, where b is the receiver bandwidth, is added to the result obtained in equation (2-37). This form is applicable throughout this report. Table 2.2 lists typical values of bandwidth correction factors.

b (kHz)	$10 \log b(\text{dB})$
1	0.00
2	3.01
3	4.77
4	6.02
5	6.99

Table 2.2 Typical values of bandwidth correction factor

For illustration, some actual line designs are considered. Table 2.3 lists the line voltages and parameters and Fig. 2.2 show the line configurations

Line Config.	Line Voltage (kV)	H (m)	D (m)	d_c (cm)	n	A (cm)
# 1	345	13.61	8.31	3.038	2	45.70
# 2	500	14.43	12.19	2.959	3	52.80
# 3	765	20.83	13.72	2.959	4	64.70
# 4	1100	21.34	15.24	3.556	8	101.60

Table 2.3 AC line voltages and parameters considered

where H is the average height of the conductors,

D is the spacing between the conductors,

d_c is the diameter of the subconductors,

n is the number of subconductors in a bundle,

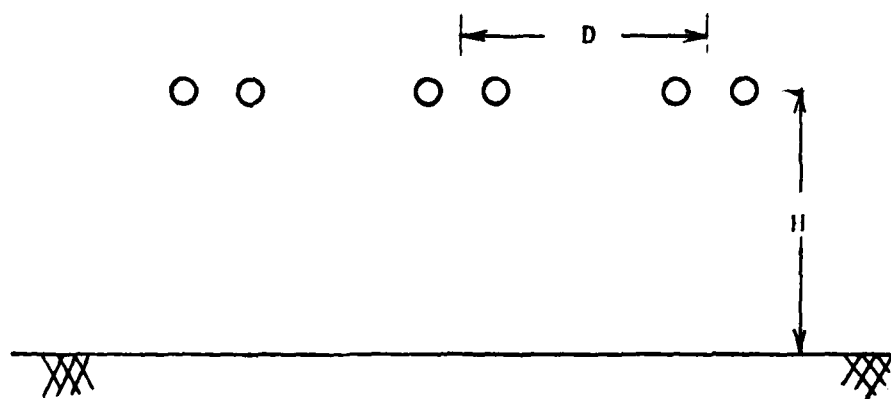


Fig. 2.2a Line configuration #1 for 345 KV

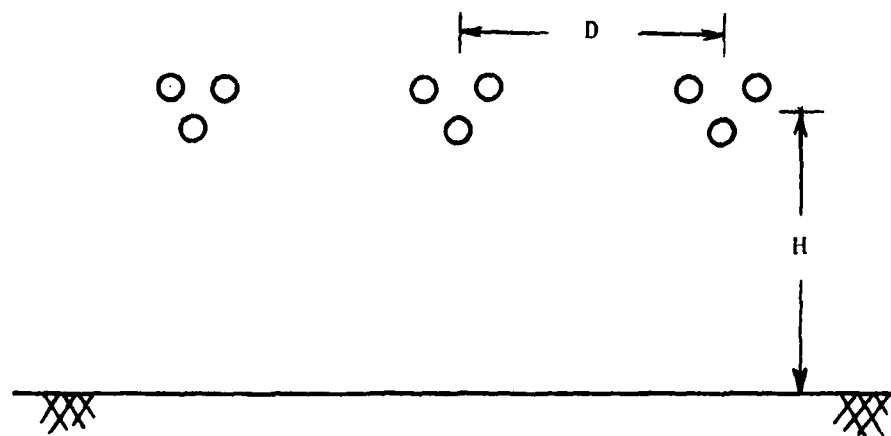


Fig. 2.2b Line configuration #2 for 500 KV

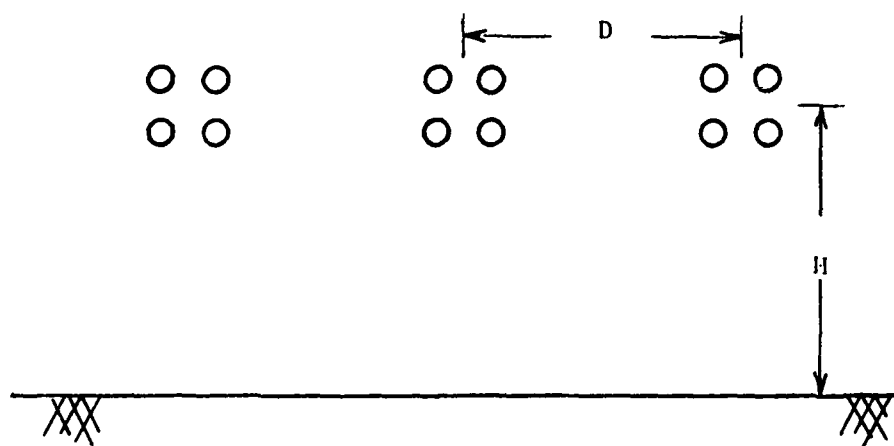


Fig. 2.2c Line configuration #3 for 765 KV

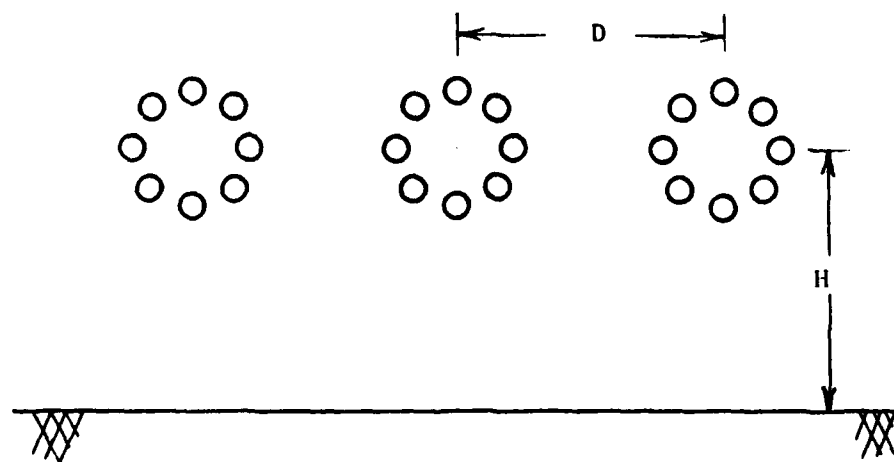


Fig. 2.2d Line configuration #4 for 1100 KV

Λ is the diameter of a bundle.

By using the modal analysis method detailed above, the RI noise level is calculated for each of the line designs listed in Table 2.3 at frequencies of 200 kHz and 500 kHz with the observer at various altitudes. Fig. 2.3 to 2.6 illustrate the characteristics of the calculated RI noise levels radiated from the AC powerlines.

2.3 Computation of Signal Strength from an NDB Transmitter

Based on the assumptions that the heights of the transmitting and receiving antenna are within a few wavelengths of the earth's surface and that they are separated by a short distance such that the curvature of the earth is negligible, a flat earth model can be used for the computation of the electric field strength of the signal from an NDB transmitter.

An initial approximate computation assumes that the earth is infinitely conducting. Later, this result is modified by multiplication by the flat earth attenuation function developed by Wait⁹, which will give the final result of the electric field strength over a finitely conducting earth. Fig. 2.7 illustrates a vertical electric monopole of length " ℓ " carrying current I located on the surface of a finitely conducting earth.

Harrington¹⁰ states that far from a current element in free space, the electric field strength is given by

$$E_{\theta} = \eta \frac{jI\ell}{2\lambda r} \cdot e^{-jkr} \cdot \sin \theta \quad (2-38)$$

and the actual average power radiated by the current element is

$$P_r = \eta \frac{2\pi}{3} \cdot \left| \frac{I\ell}{\lambda} \right|^2 \quad (2.39)$$

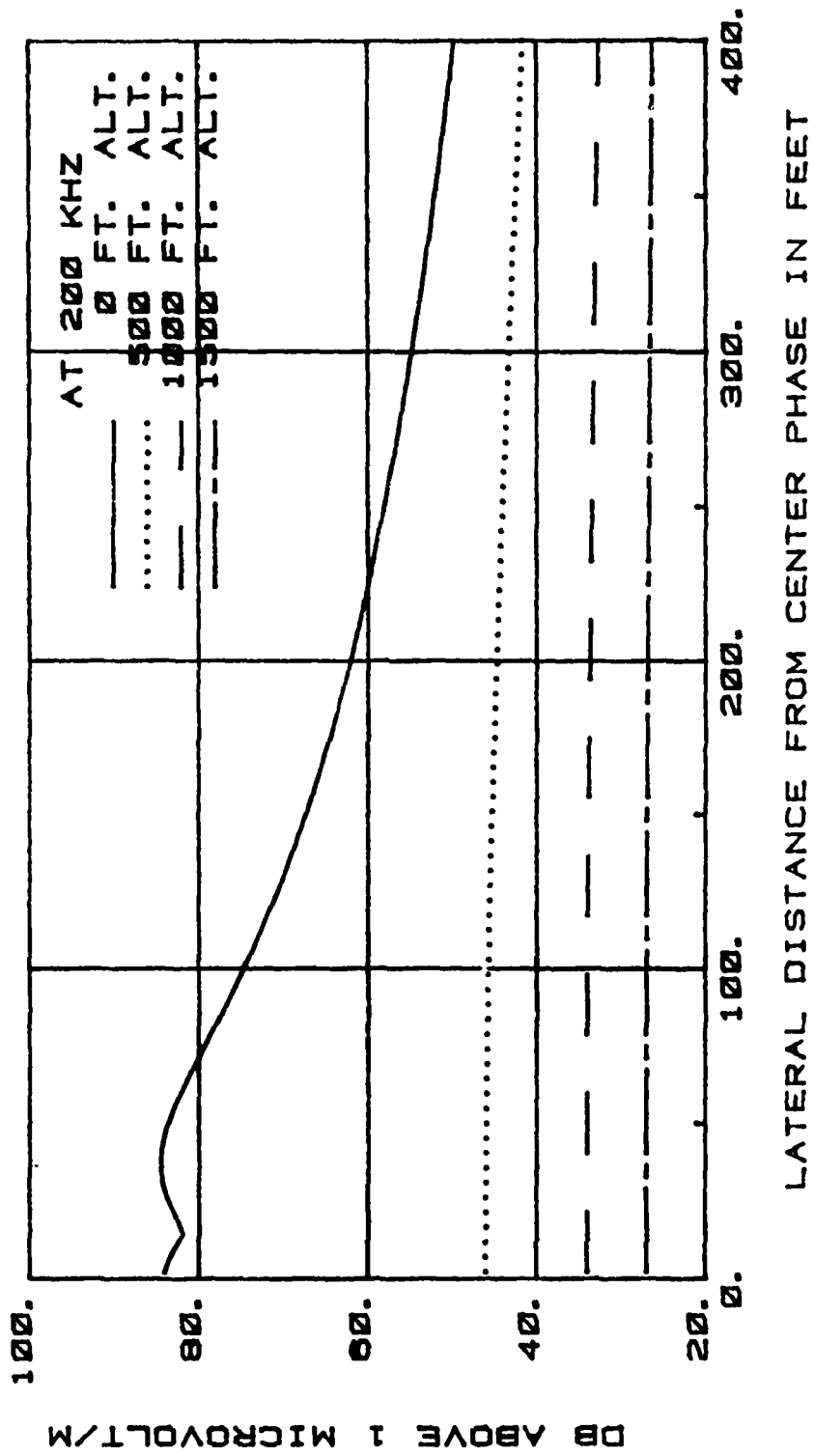


Fig. 2.3a Calculated RI noise profile for 345 kV AC powerline at 200 kHz
under heavy rain condition

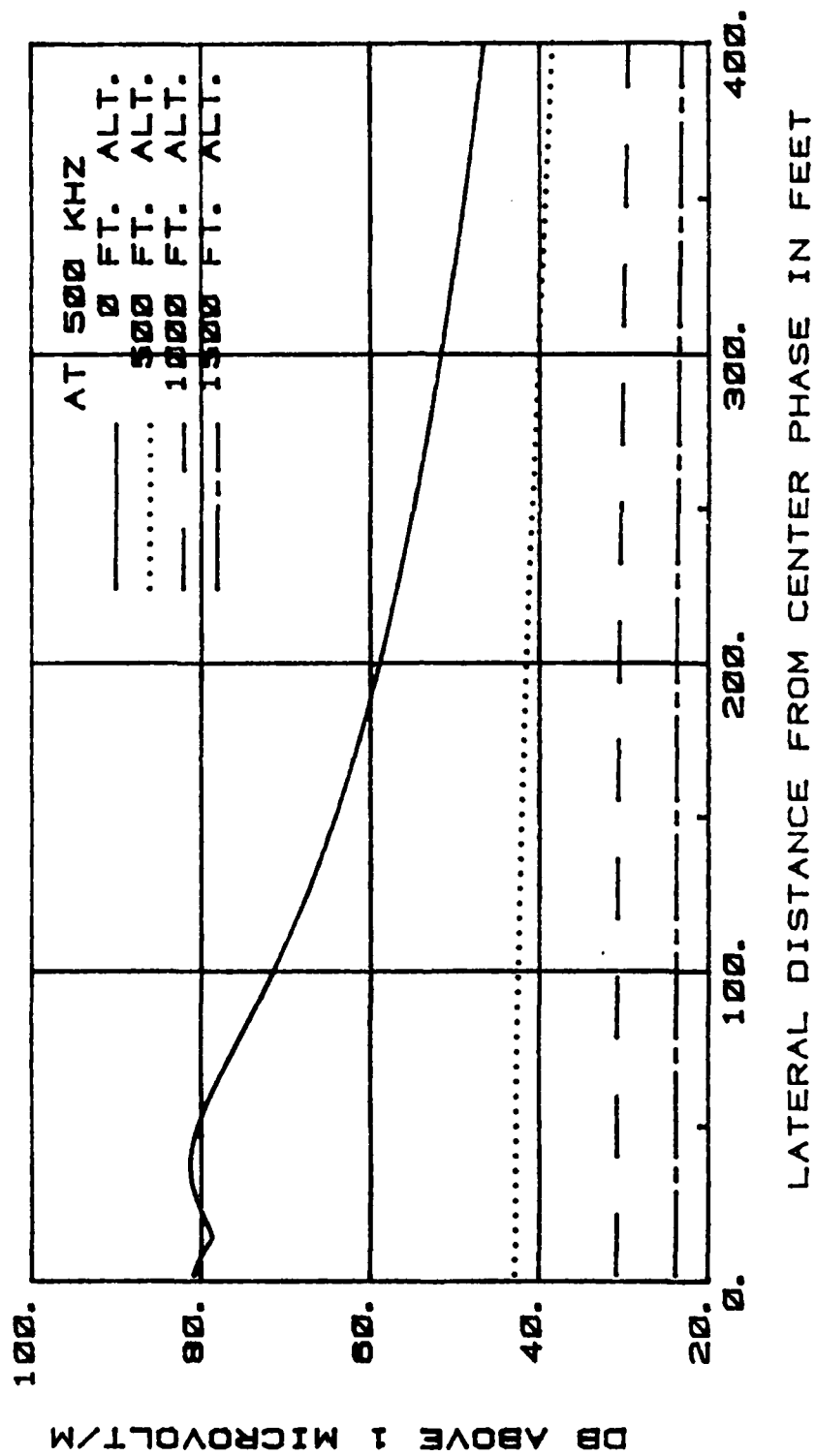


Fig. 2.3b Calculated RI noise profile for 345 kV AC powerline at 500 kHz under heavy rain condition

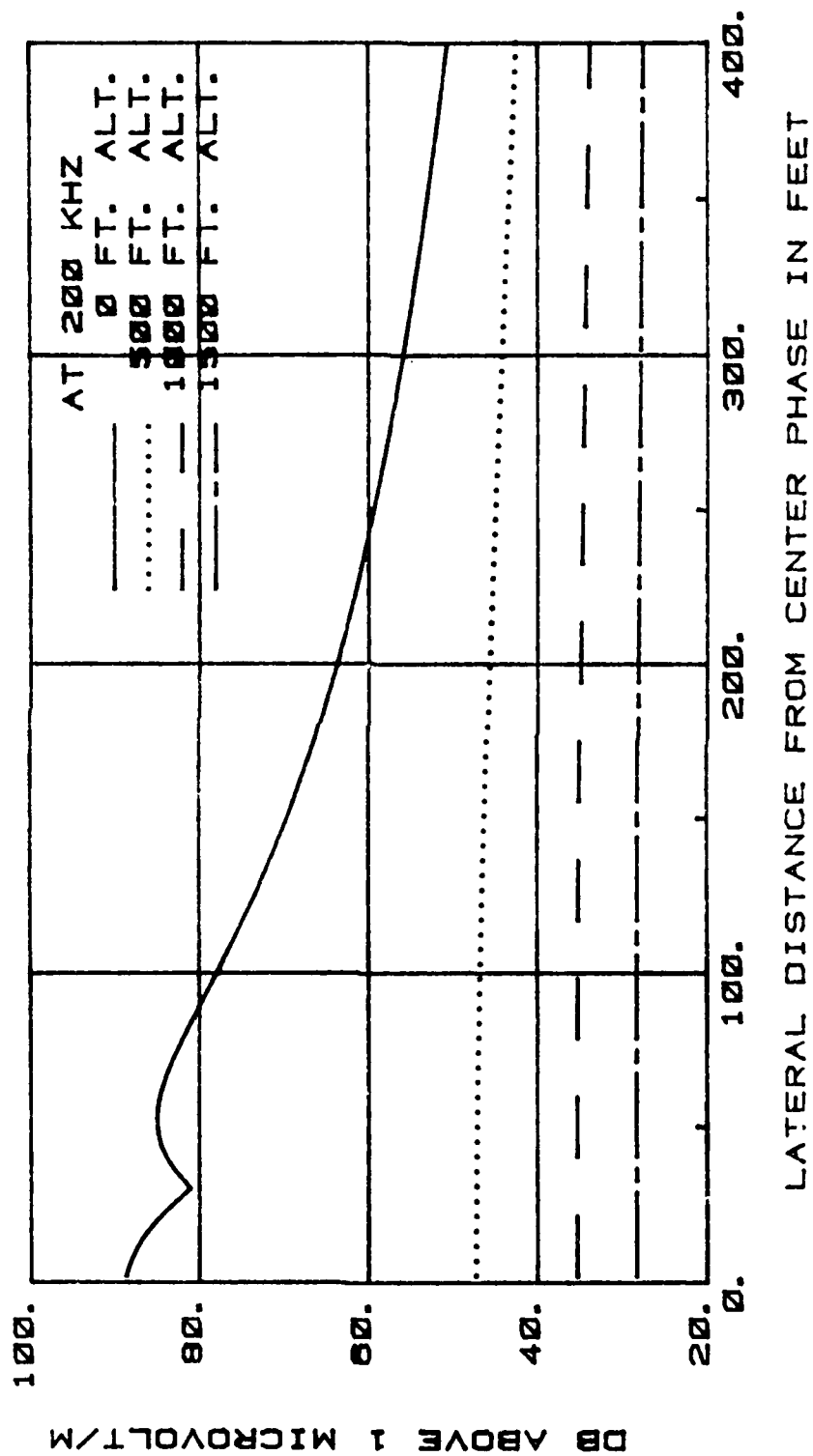


Fig. 2.4a Calculated RI noise profile for 500 KV AC powerline at 200 KHz under heavy rain condition

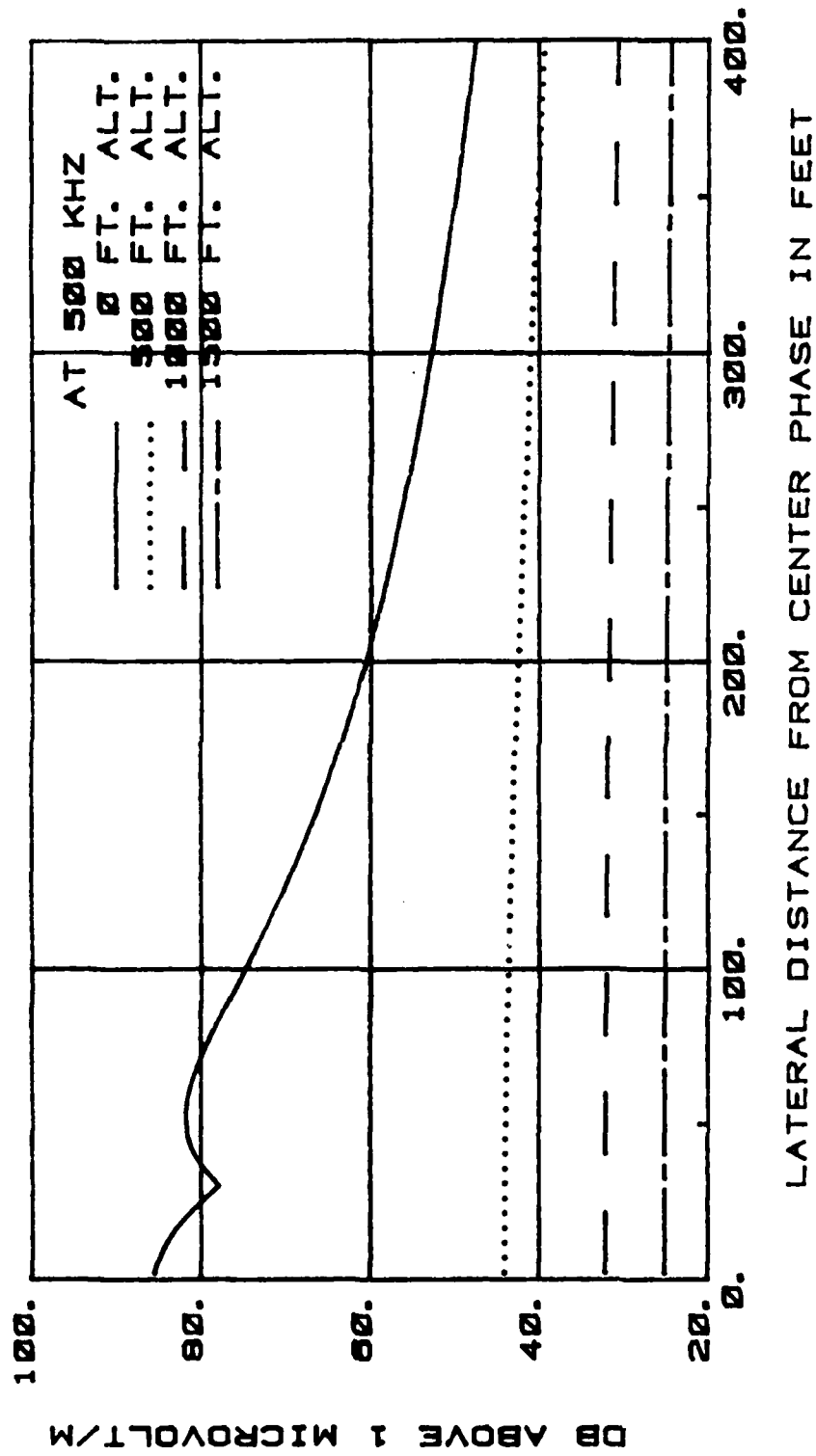


Fig. 2.4b Calculated RI noise profile for 500 kV AC powerline at 500 kHz under heavy rain condition

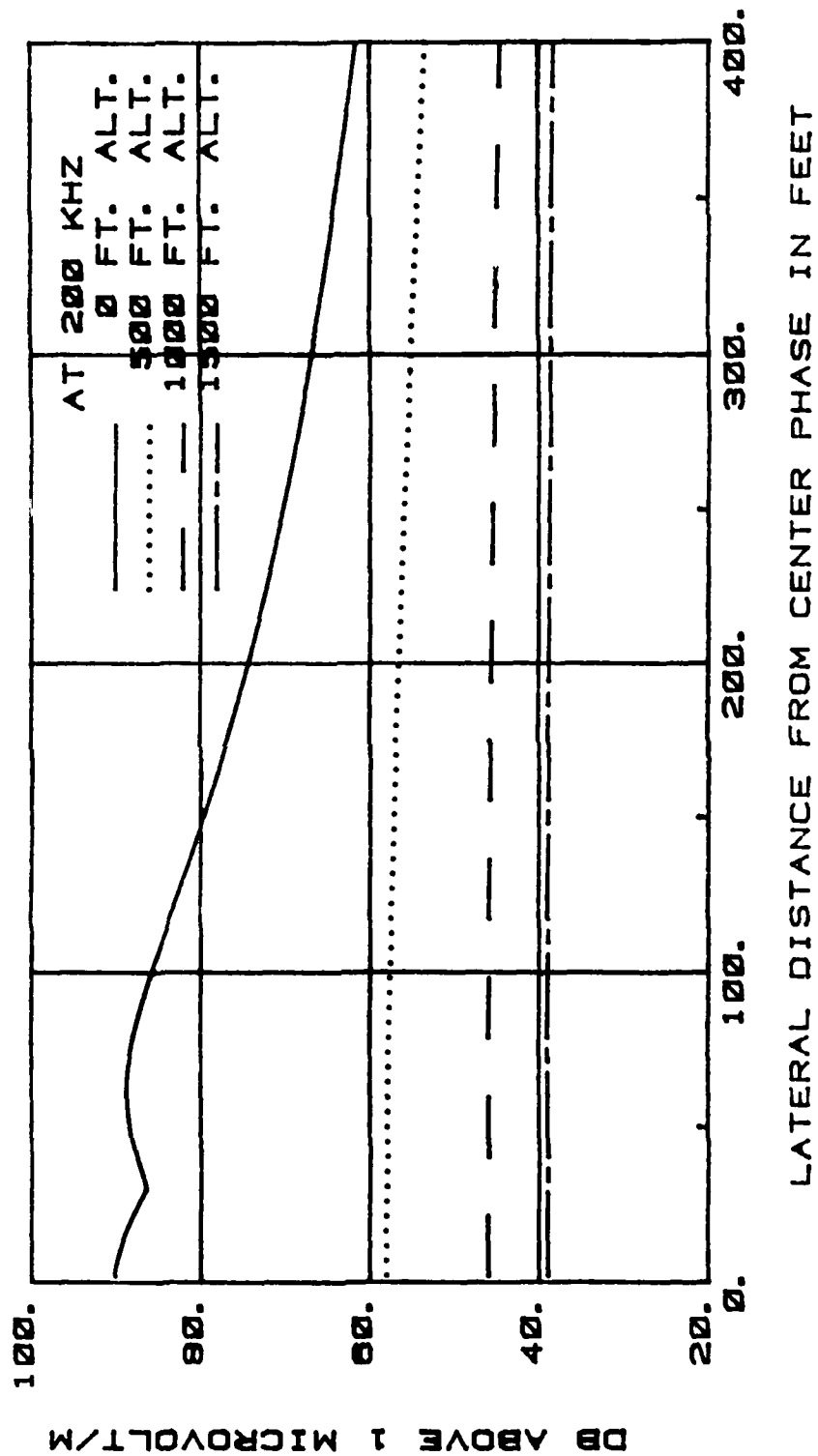


Fig. 2.5a Calculated RI noise profile for 765 kV AC powerline at 200 kHz under heavy rain condition

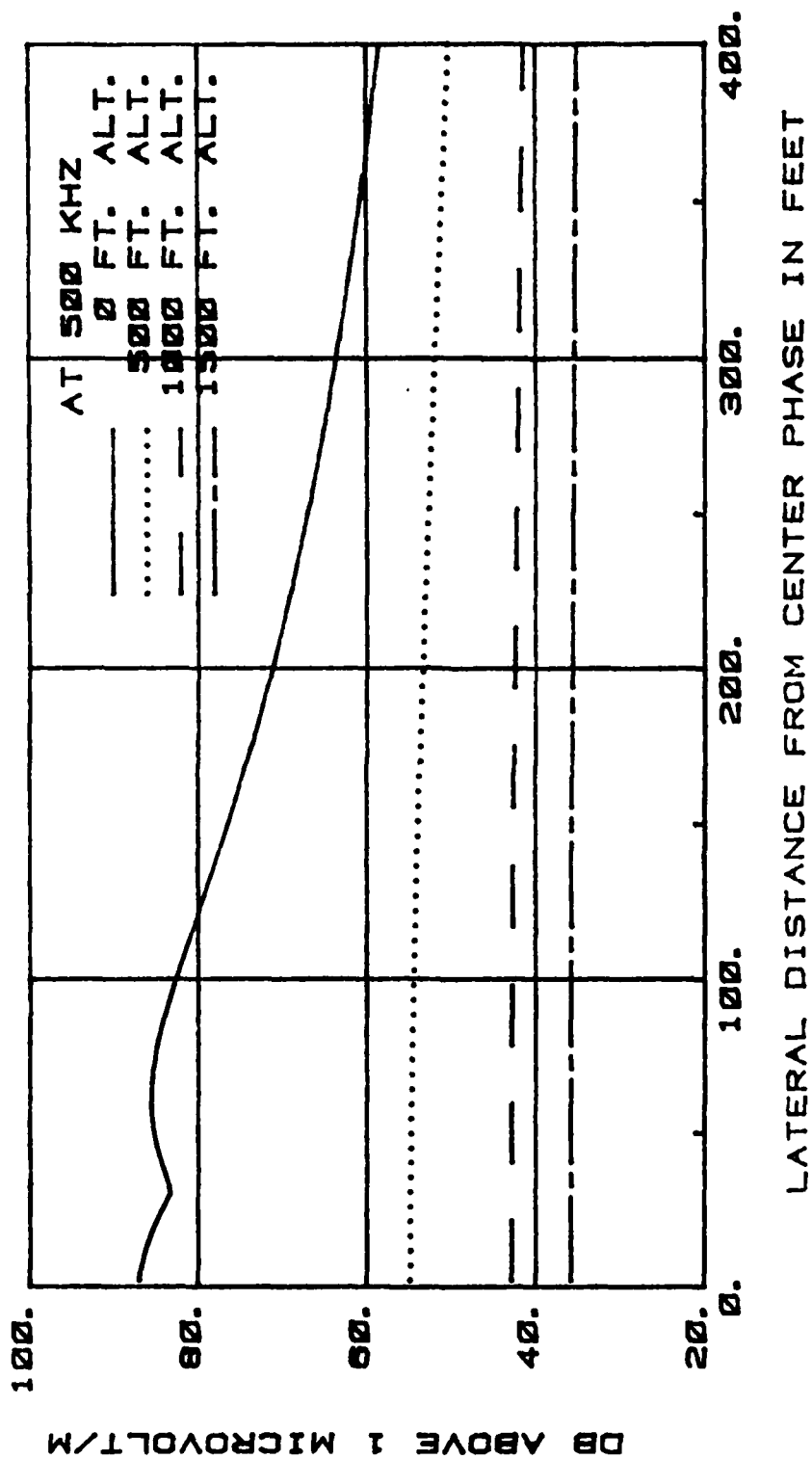


Fig. 2.5b Calculated RI noise profile for 765 kV AC powerline at 500 kHz under heavy rain condition

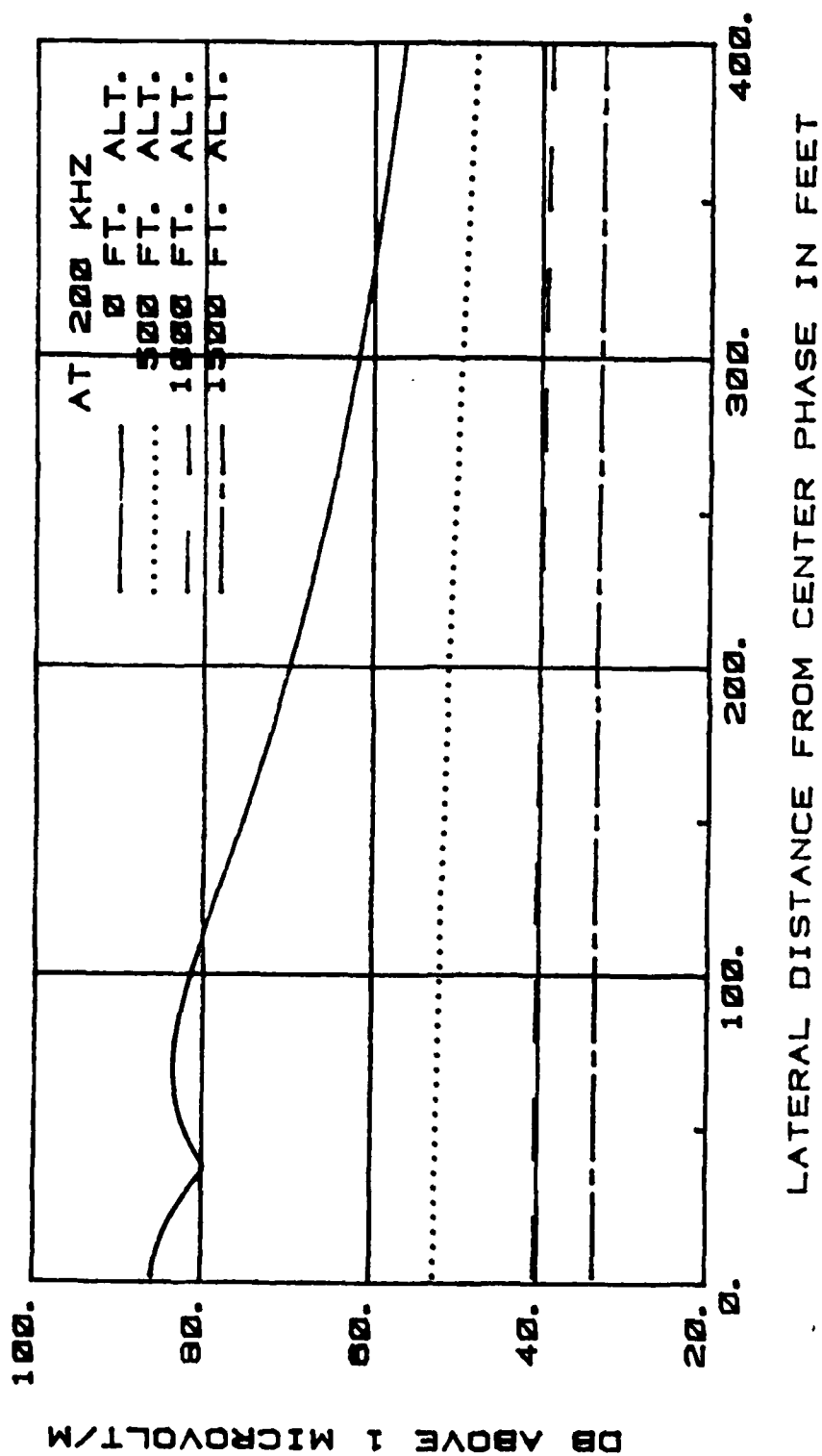


Fig. 2.6a Calculated RI noise profile for 1100 kV AC power-line at 200 kHz under heavy rain condition.

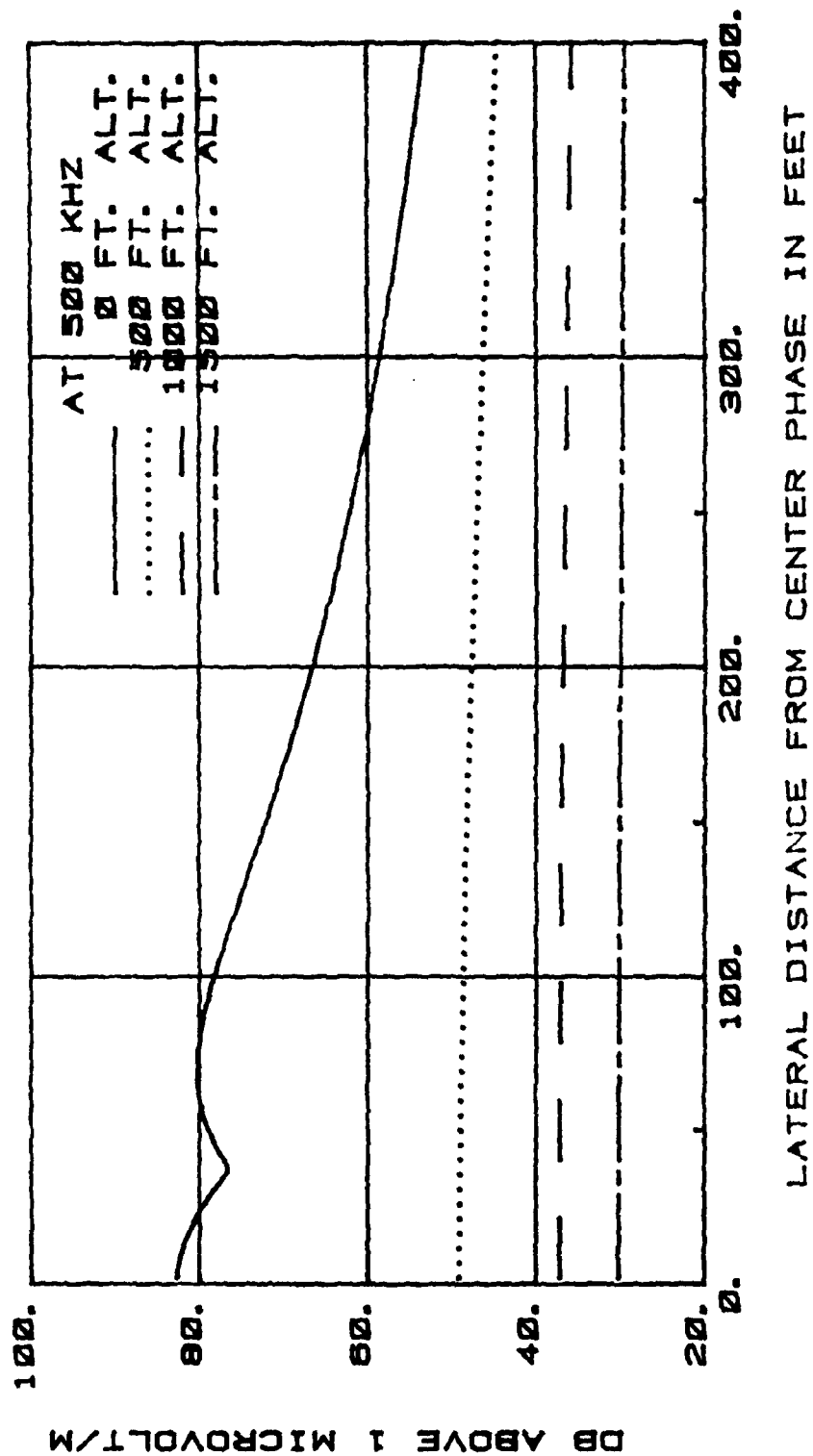


Fig. 2.6b Calculated RI noise profile for 1100 kV AC powerline at 500 kHz under heavy rain condition.

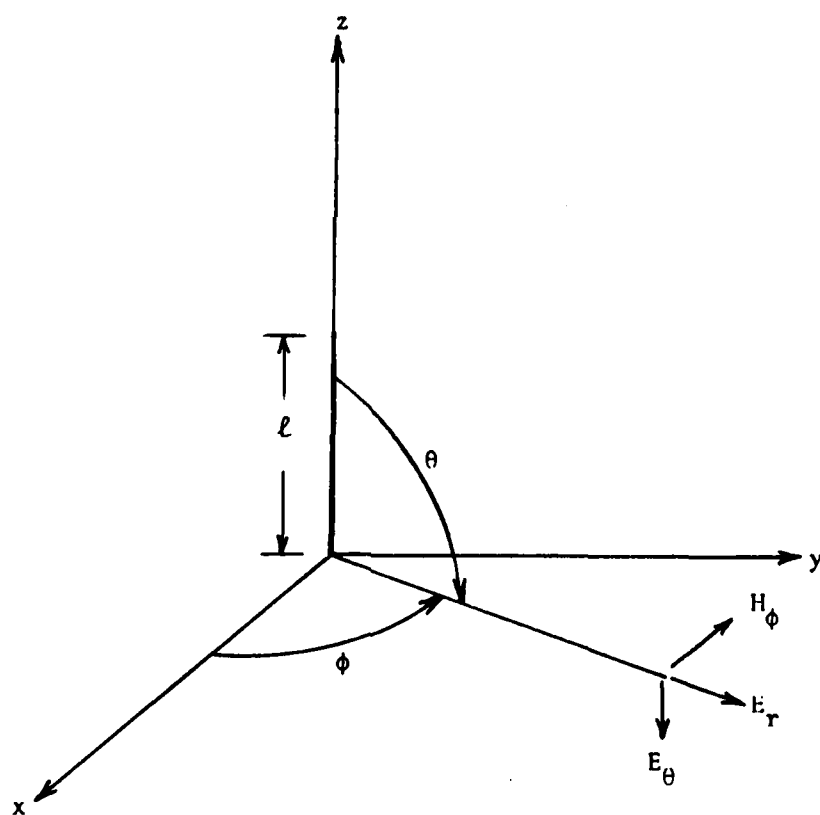


Fig. 2.7 Geometry of flat earth model

where: η is the wave impedance of free space,

λ is the wavelength,

k is the wave constant

r is the distance from the transmitting antenna.

Since we are interested only in the magnitude of the electric field strength near the ground, equation (2-38) can be simplified into

$$E_{\theta} = \eta \frac{I\ell}{2\lambda r} \quad (2-40)$$

If the earth is assumed to be present but infinitely conducting, due to image theory, the far field term will be exactly doubled. Therefore

$$E_{\theta} = \eta \frac{I\ell}{\lambda r} \quad (2-41)$$

and the corresponding value of the actual average power radiated is given by

$$P_r = \eta \frac{4\pi}{3} \cdot \left| \frac{I\ell}{\lambda} \right|^2 \quad (2-42)$$

From equation (2-42) above,

$$I\ell = \lambda \sqrt{\frac{3P_r}{4\eta\pi}} \quad (2-43)$$

Substituting equation (2-43) into (2-41) yields

$$E_{\theta} = \sqrt{\frac{3\eta}{4\pi}} \cdot \sqrt{\frac{P_r}{r}} = 9.487 \sqrt{\frac{P_r}{r}} \quad (2-44)$$

Finally, by multiplying equation (2-44) by the flat earth attenuation function, the resulting electric field strength over a finitely conducting earth is

$$E = \frac{9.487 \sqrt{P_r}}{r} (1.00 - R_o \delta c^2 \operatorname{erfc}(z)) \quad (2-45)$$

where: E is the electric field strength in $\mu\text{V/m}$,

P_r is the effective radiated power in watts,

$$\delta = \frac{\sqrt{\eta - 1}}{\eta} \quad (2-46)$$

$$\text{and } \eta = \epsilon_r - j \frac{1.8 \times 10^7 \cdot \sigma}{f} \quad (2-47)$$

with ϵ_r and σ the relative permittivity and conductivity in mho/m of the earth respectively, f the frequency in kilohertz,

$$R_o = e^{j\pi/4} \sqrt{\frac{\pi k D}{2}} \quad (2-48)$$

$$\text{and } D = \sqrt{r^2 + (h_1 - h_2)^2} \quad (2-49)$$

with $k = 2\pi/\lambda$, λ being the free space wavelength, and h_1 and h_2 the antenna heights; erfc is the complementary error function as defined by Abramowitz and Stegun¹¹ and

$$z = e^{j\pi/4} \cdot \sqrt{\frac{kD}{2}} \cdot \delta \cdot \left(1.00 + \frac{h_1 + h_2}{\delta D}\right) \quad (2-50)$$

Assuming that the transmitting antenna is a 40-foot high vertical radiator, the relative permittivity of earth is 10.0 and the ground conductivity be 10.0 mmho/m, Fig. 2.8 to 2.11 illustrate the patterns of the electric field strength for NDB transmitters with an effective radiated power (ERP) of 0.05 watt, 0.10 watt, 0.5 watts and 1.0 watt respectively, at the frequencies of 200 kHz and 500 kHz with the receiver altitude at ground level and at 1500 feet above ground. Appendix D details program signal listing for the computation of the electric field strength from an NDB for short distances under the above conditions.

2.4 Prediction of the Critical Distance Where the Ratio of Desired Signal/Undesired Noise is 15 dB

The desired signal is the signal from the NDB transmitter and the

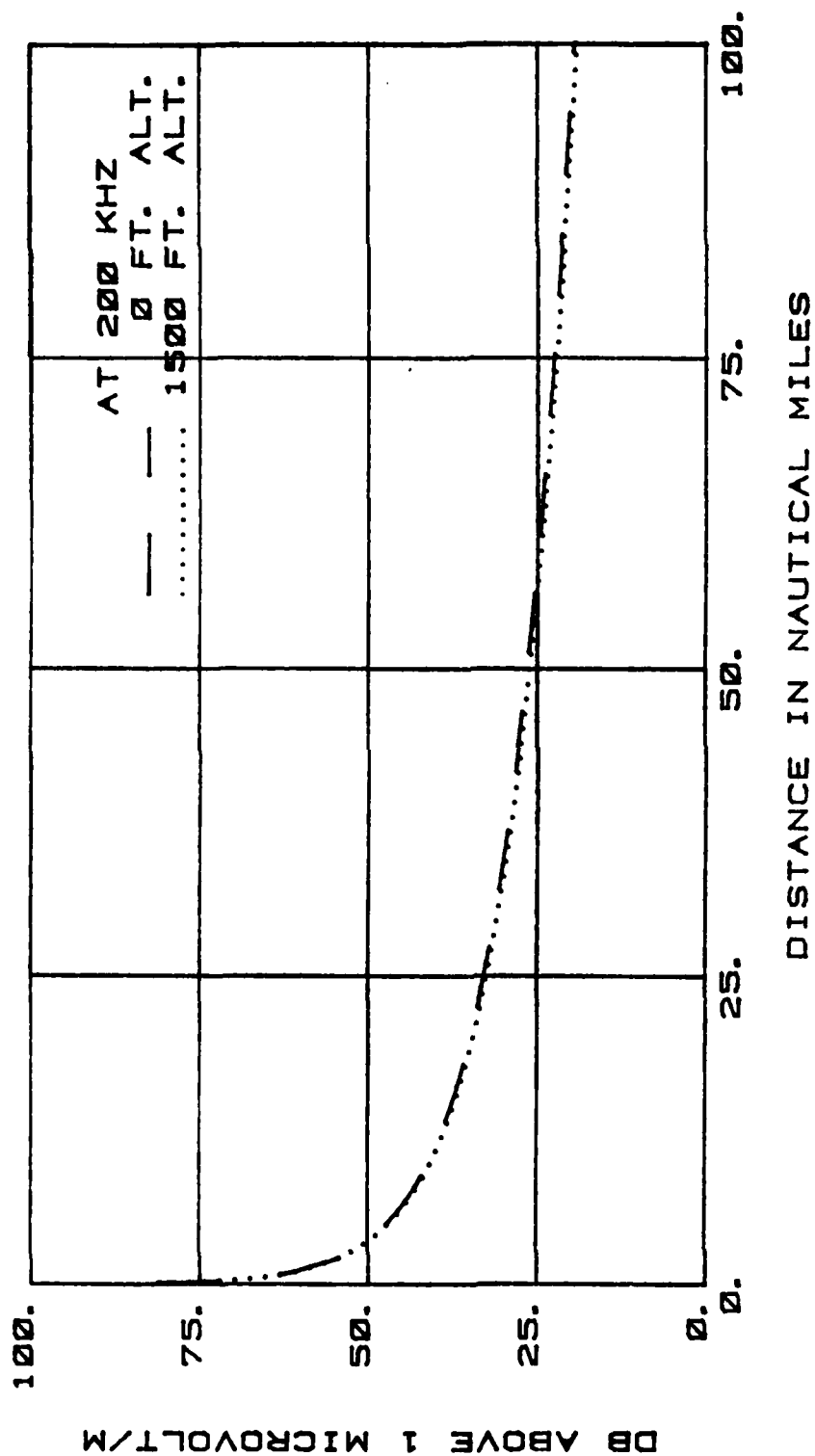


Fig. 2.8a Transmitter; ERP = 0.05 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0$ mho/m,
 $f = 200$ kHz.

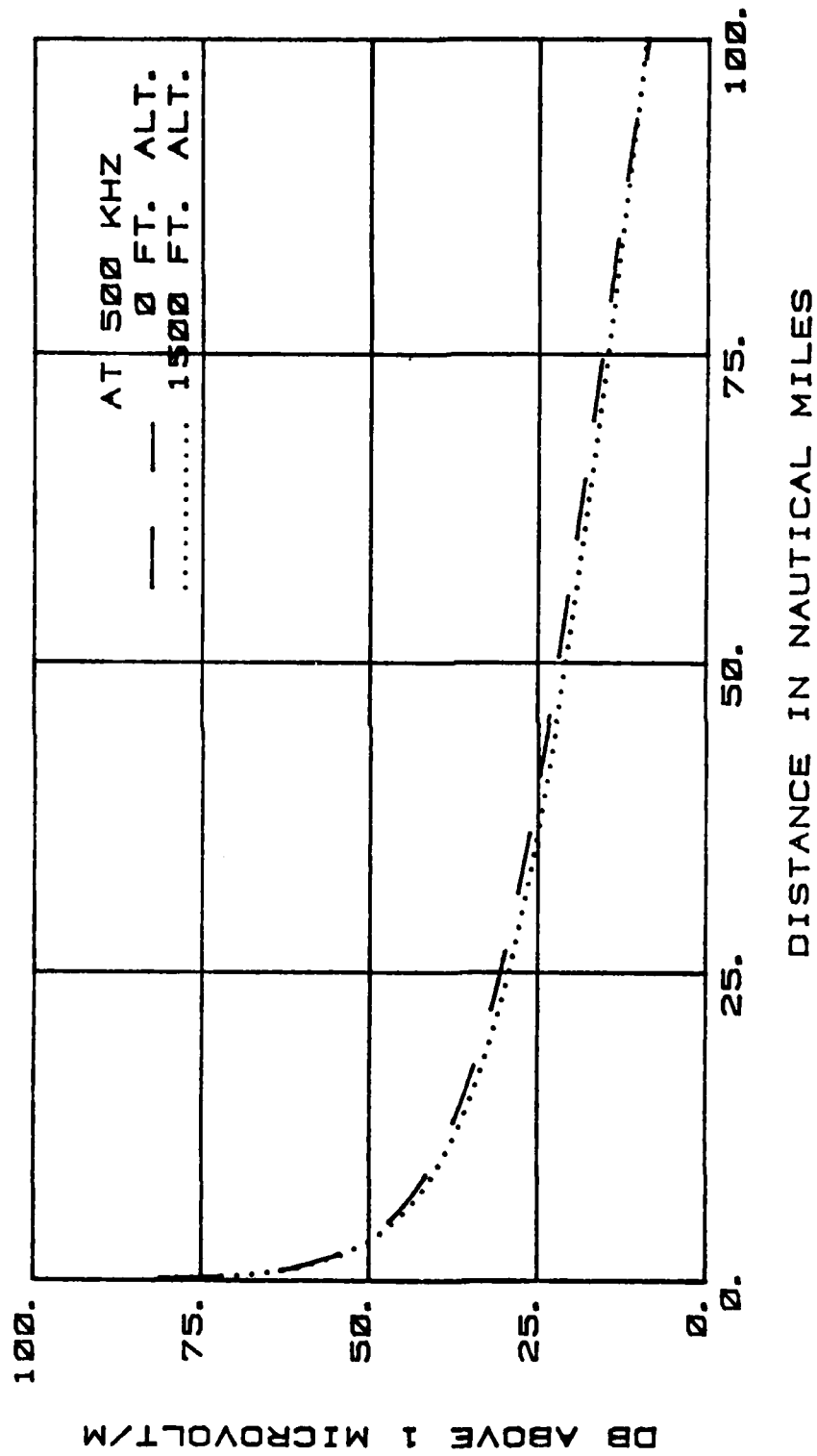


Fig. 2.8b Transmitter; ERP = 0.05 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0$ mmho/m, $f = 500$ kHz.

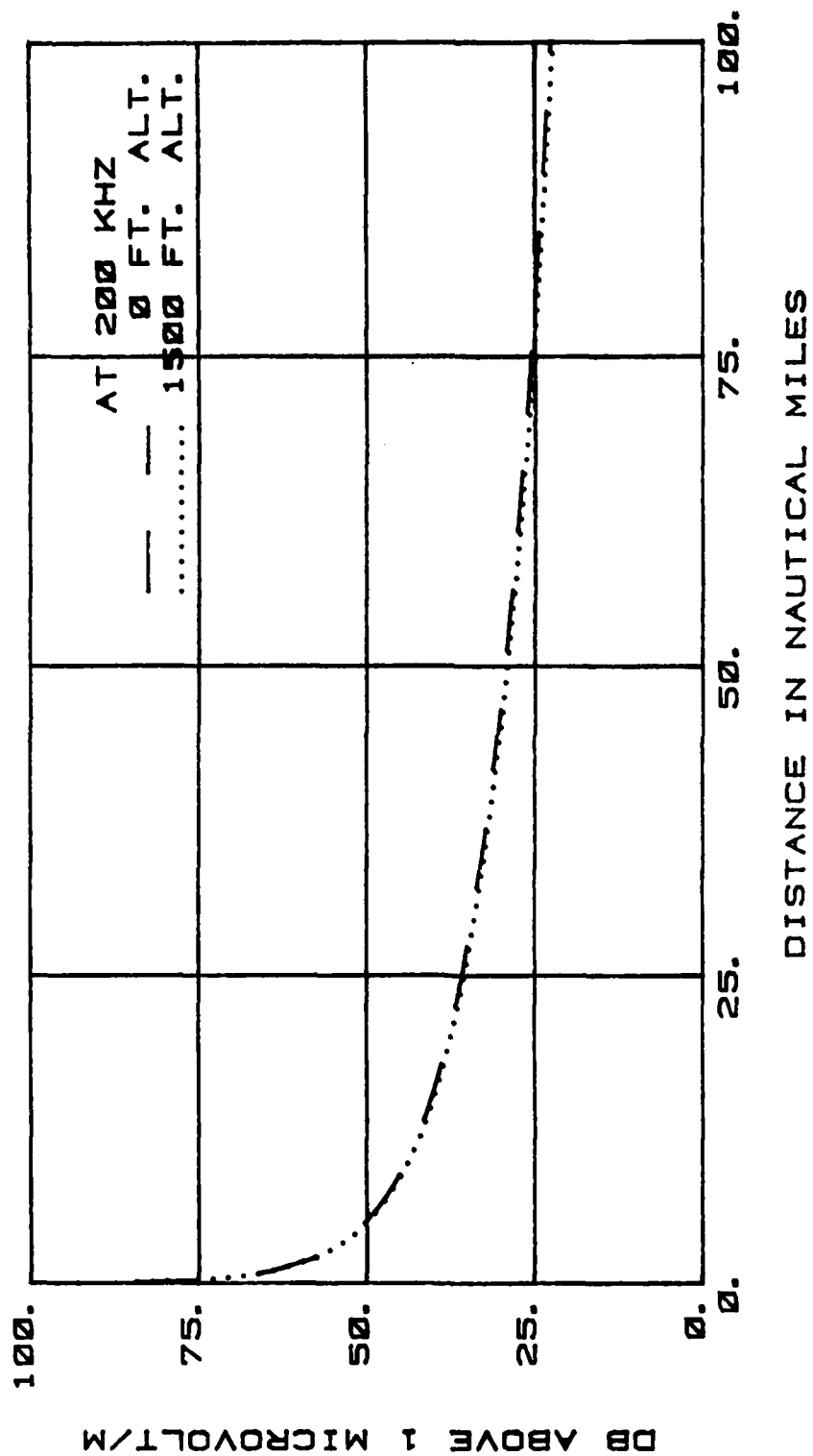


Fig. 2.9a Transmitter; ERP = 0.1 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0$ mmho/m, $f = 200$ kHz.

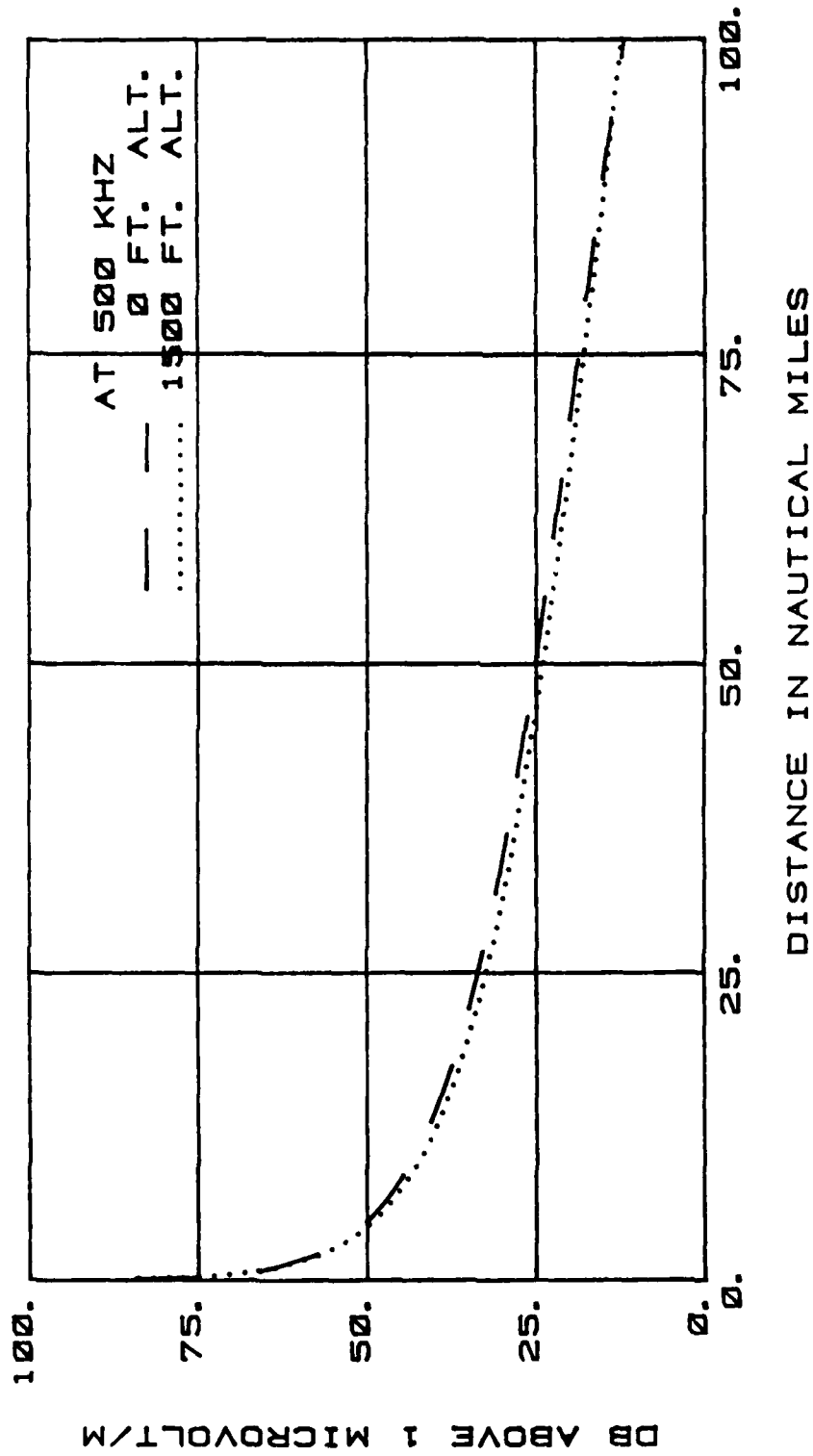


Fig. 2.9b Transmitter; ERP = 0.1 watt, $\epsilon_T = 10.0$, ground $\sigma = 10.0$ mmho/m, $f = 500$ kHz.

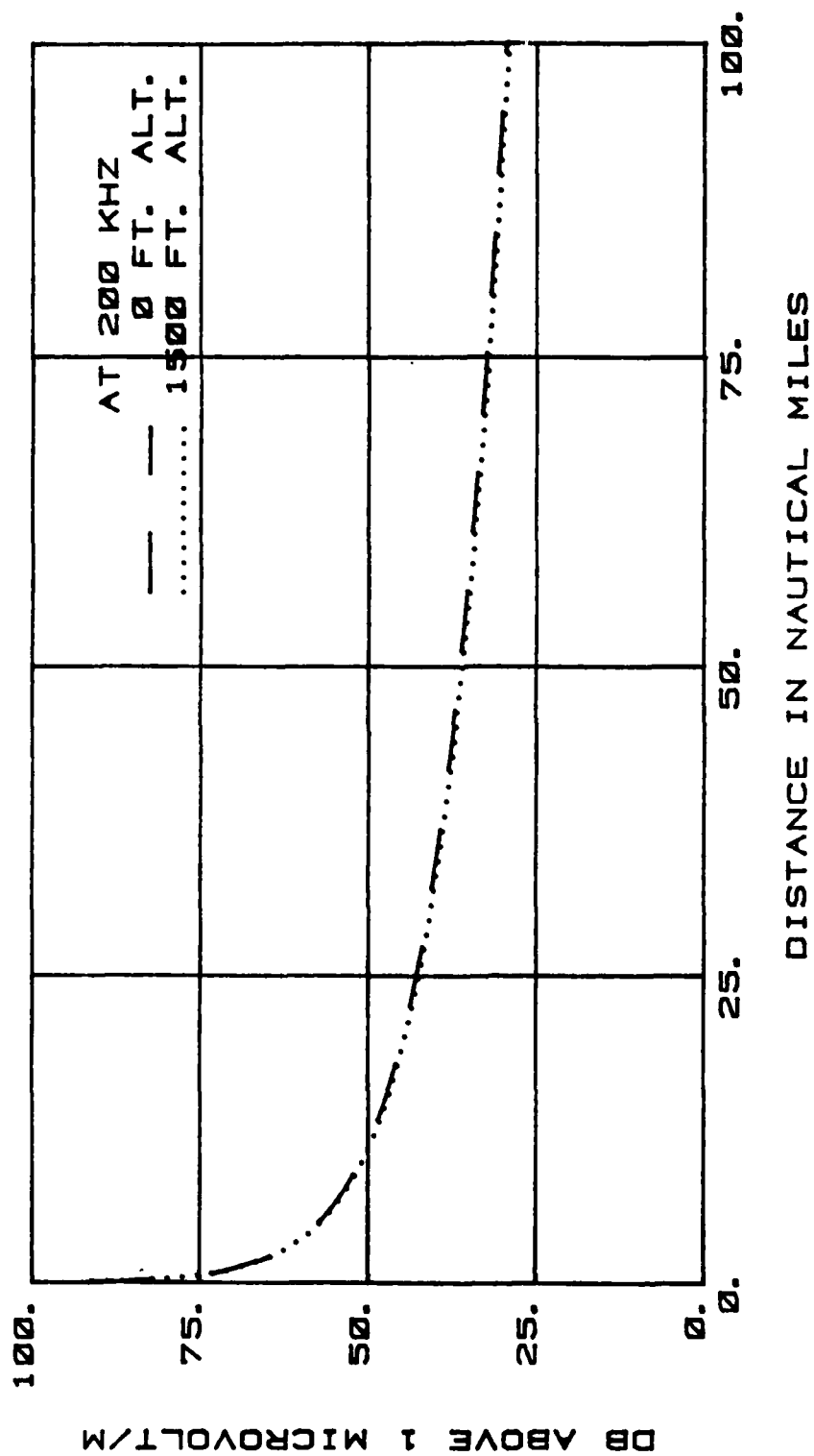


Fig. 2.10a Transmitter; ERP = 0.5 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0$ mmho/m,
 $f = 200$ kHz.

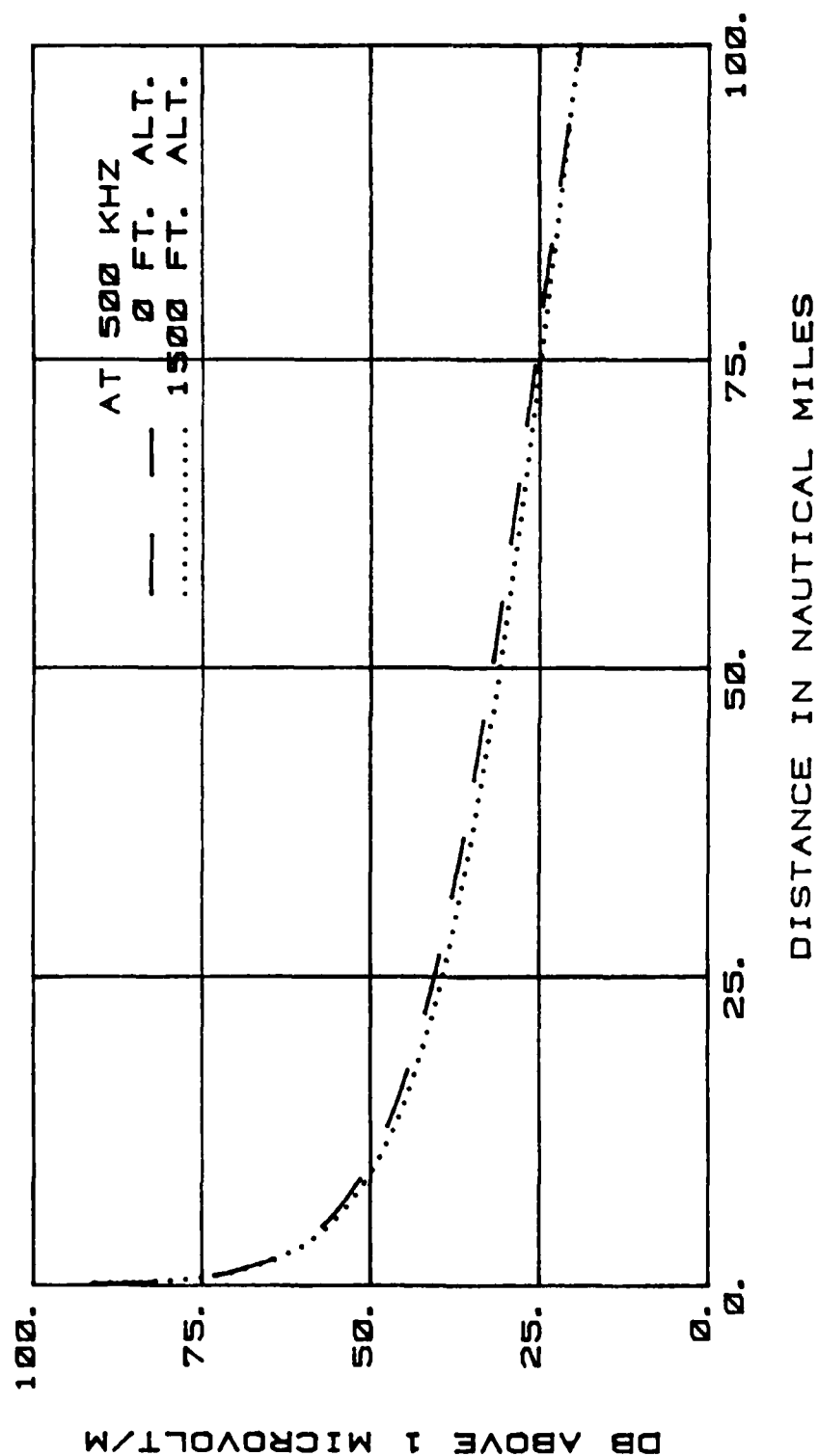


Fig. 2.10b Transmitter; ERP = 0.5 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0$ mmho/m, $f = 500$ kHz.

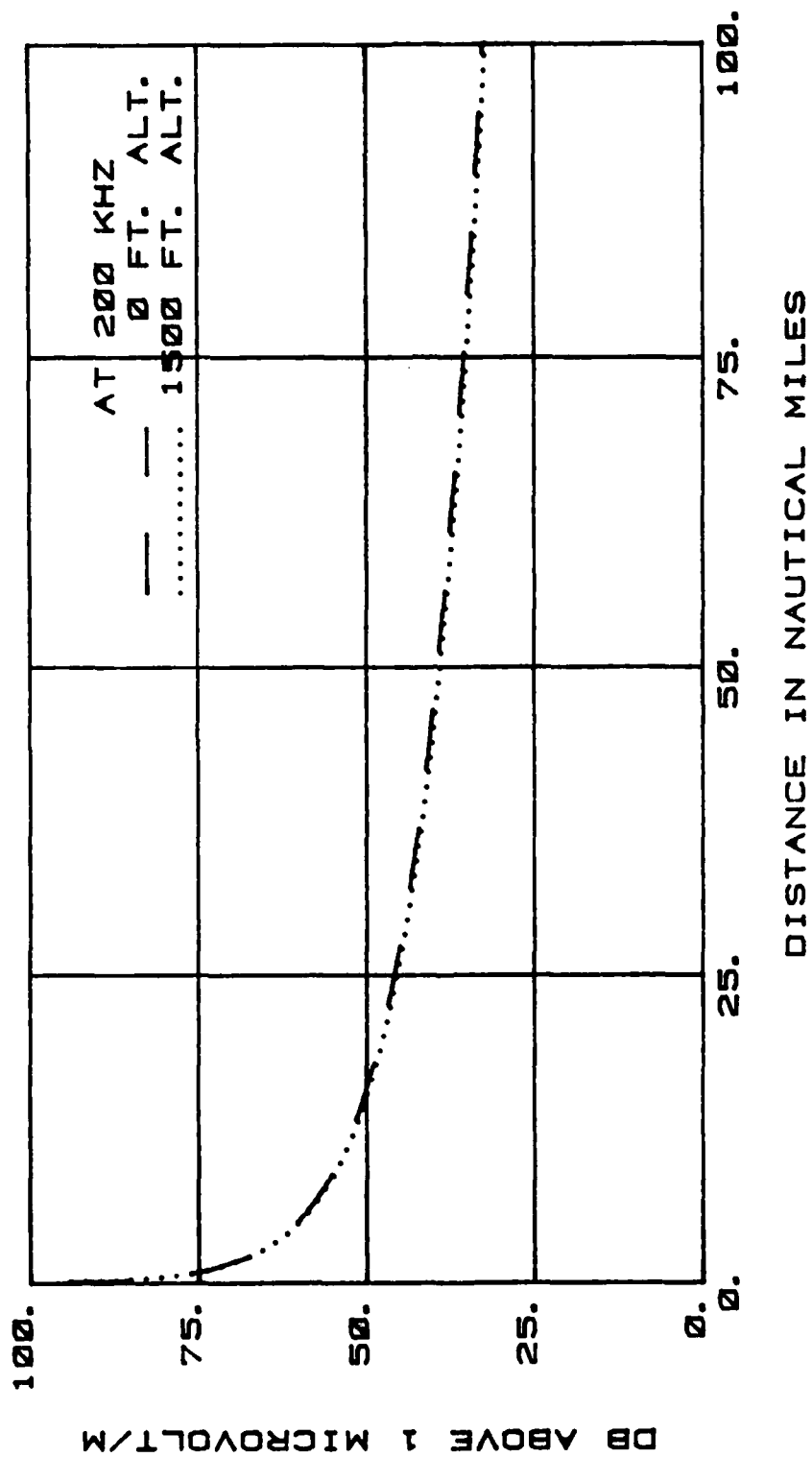


Fig. 2.11a Transmitter; ERP = 1.0 watt, $\epsilon_T = 10.0$, ground $\sigma = 10.0$ mho/m,
 $f = 200$ kHz.

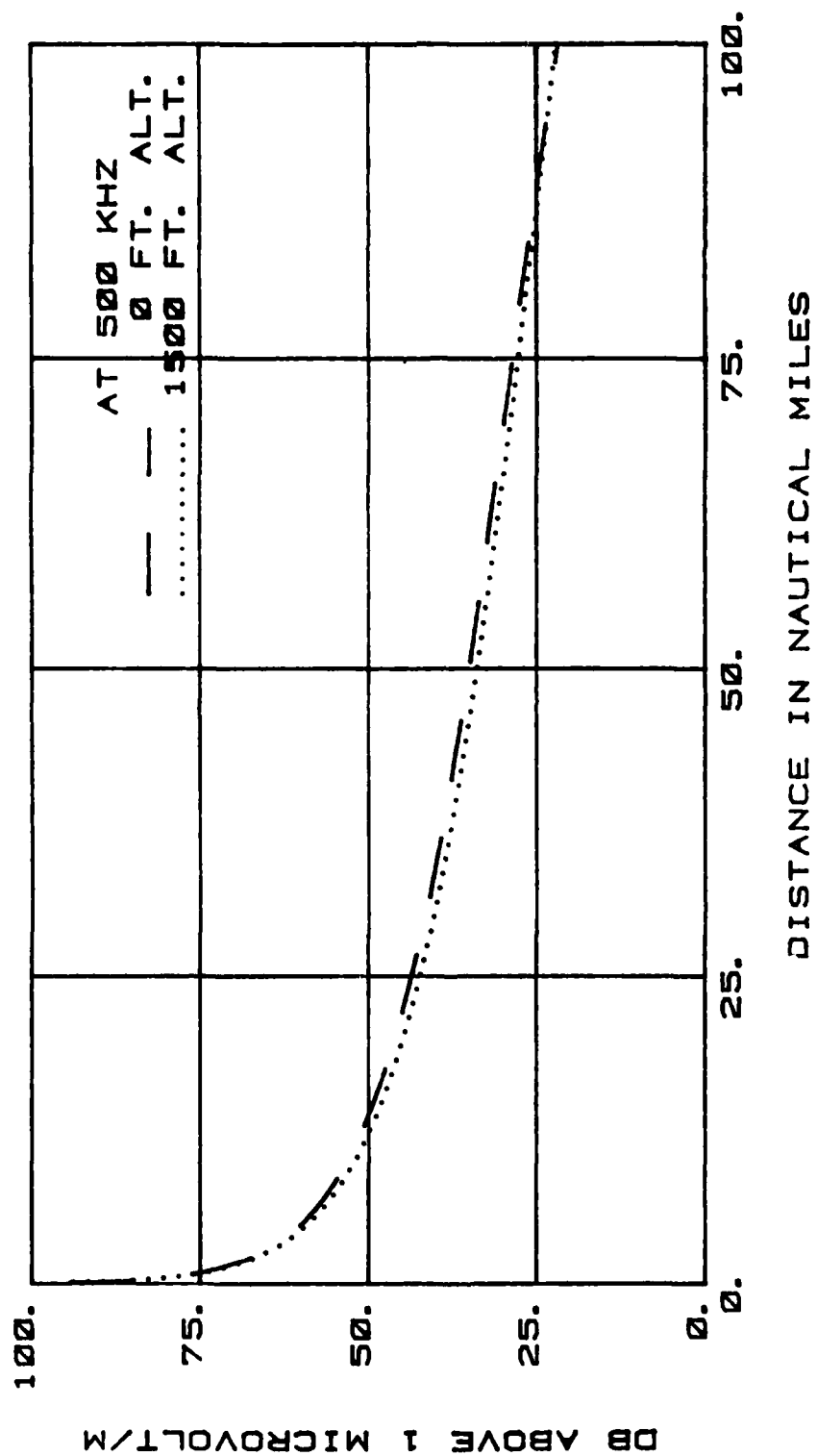


Fig. 2.11b Transmitter; ERP = 1.0 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0$ mmho/m, $f = 500$ kHz.

undesired signal is the RI noise from the AC powerlines. The former has been dealt with in Section 2.3 and the latter in Section 2.2. Consider the scenario illustrated in Fig. 2.12. The scenario in question illustrates a worst case condition where the path of the aircraft flying over the powerline is perpendicular to it, the aircraft and the NDB transmitter are on the opposite side of the powerline and a heavy rain is falling. Let the distance separating the NDB transmitting antenna and the powerlines be y nautical miles, the lateral distance between the powerlines and the location of the receiver (aircraft) be x feet and let the receiver be at h feet above ground. For various line designs mentioned in Section 2.2 and different values of ERP of NDB transmitter covered in Section 2.3, Fig. 2.13 to 2.24 indicate the critical distance x feet where the ratio of the desired signal/undesired noise is 15 dB with the receiver at various altitudes.

For example, in Fig. 2.23a, where the ERP of the NDB is 1 watt and the line voltage is 765 kV, if the distance separating the NDB and the powerline is 10 NM, the critical distance for an aircraft flying at an altitude of 1500 feet is about 300 feet from the line.

After examination of Figures 2.13 to 2.24 it will be noticed that the critical distance, and thus the RI noise level, increases as line voltage is increased from 345 kV to 500 kV to 765 kV, but decreases as the voltage is further increased to 1100 kV. The reason for this is that the 1100 kV line considered has 8 subconductors, while the 765 kV line has only 4 (see Fig. 2.2, Table 2.3). This causes the maximum electric field for the 1100 kV line to be less than that for the 765 kV line, thus reducing the RI noise level.

2.5 Conclusion

At ground level, the radiated RI noise is vertically polarized. However, at any other location in space, the radiated RI noise is not entirely vertically polarized. In determining the critical distance, which involves the computation of desired signal/undesired noise ratio, no attempt is made to take the RI noise component aligned with the vertical direction. Instead, a worst case condition is considered in which only the magnitudes of both fields are taken into account.

In computing the RI noise from the powerlines, a quasi-static condition is assumed. This is valid if the wavelength of the frequency under consideration is large compared to powerline parameters (height and phase spacing) and to the distance between the powerlines and the measuring points. Thus, at any point too far from the lines, the validity of this assumption is questionable. However, for completeness, low ERP and large distances are being considered in this report. Fig. 2.13 to 2.24 have indicated that for a range of low ERP and the line designs considered, if the location of the powerline is close to an NDB, the critical distance is small at any receiver altitudes. Thus it can be concluded that if a powerline is close to an NDB transmitter, the RI noise radiated by the powerline will practically cause no appreciable effect to an aircraft flying past it.

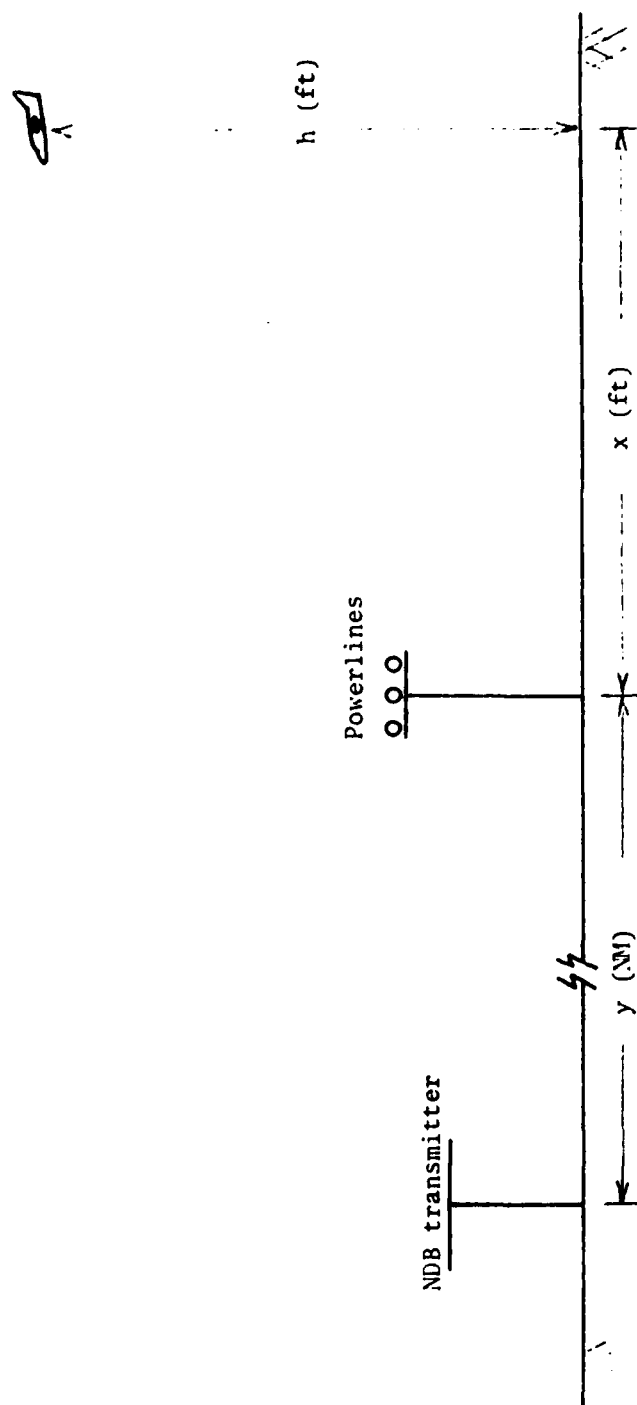


Fig. 2.12 A scenario of an aircraft flying over powerlines with an NDB transmitter nearby.

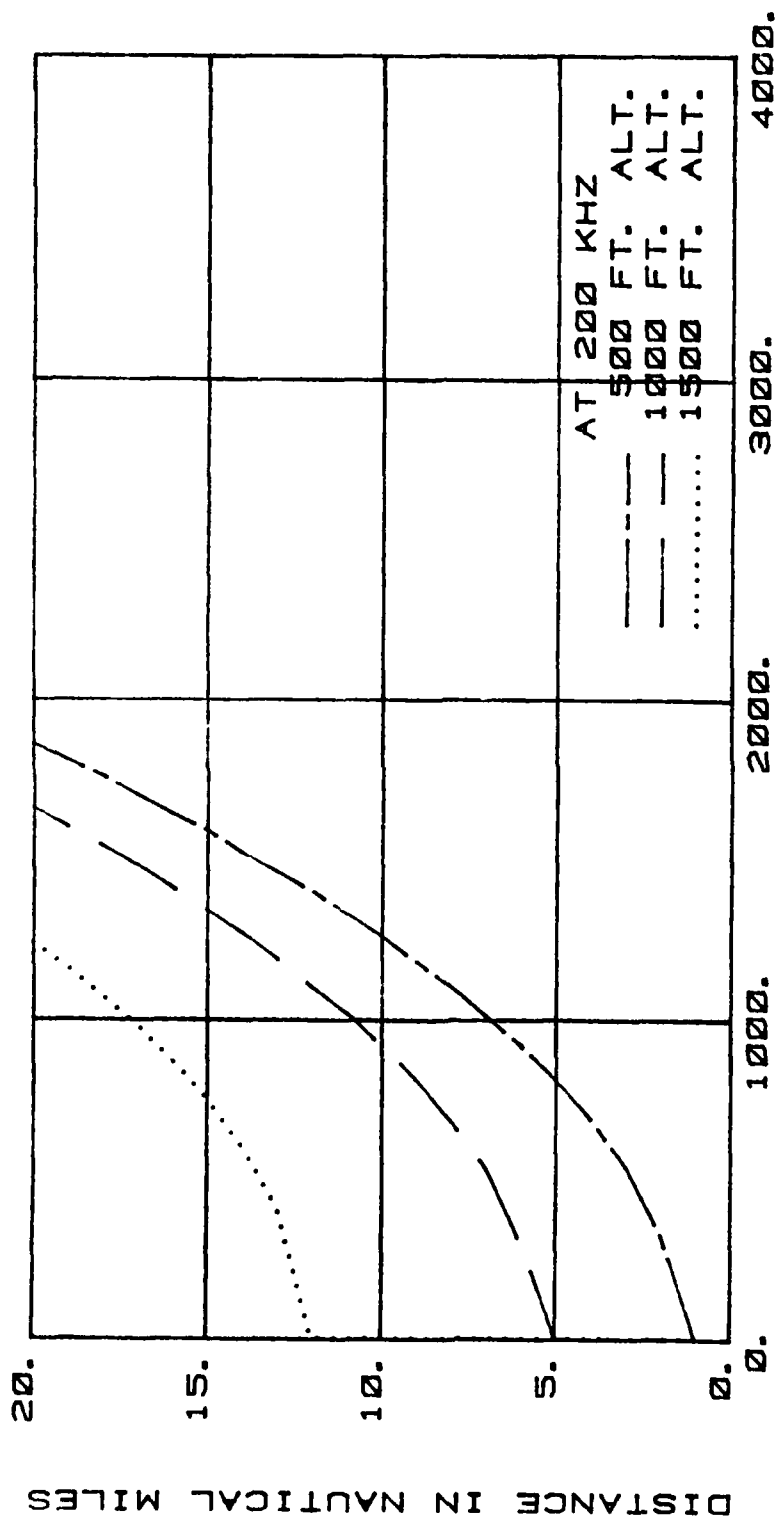
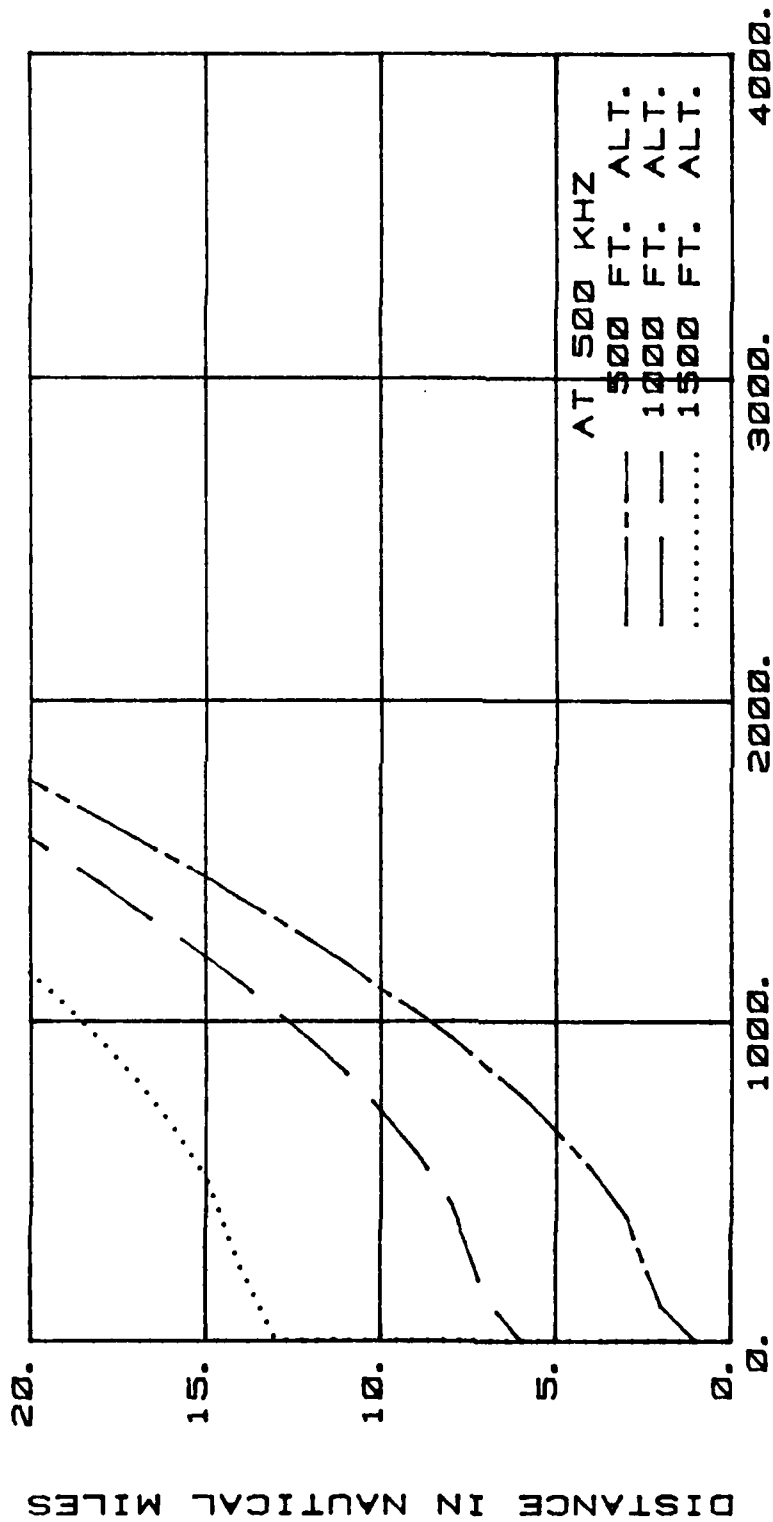


Fig. 2.13a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 345 kV, $f = 200$ kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.13b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 345 kV, $f = 500$ kHz, under heavy rain condition.

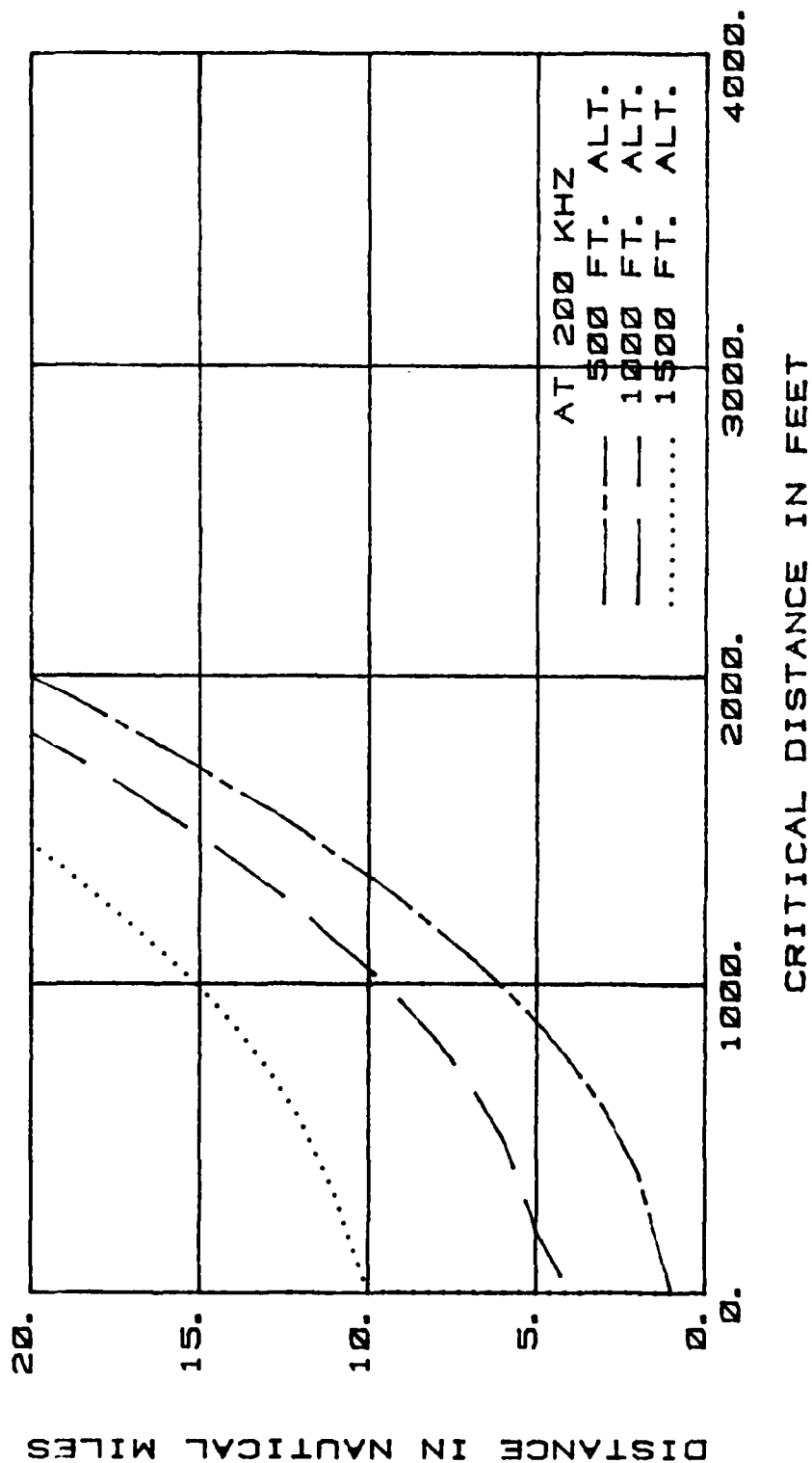
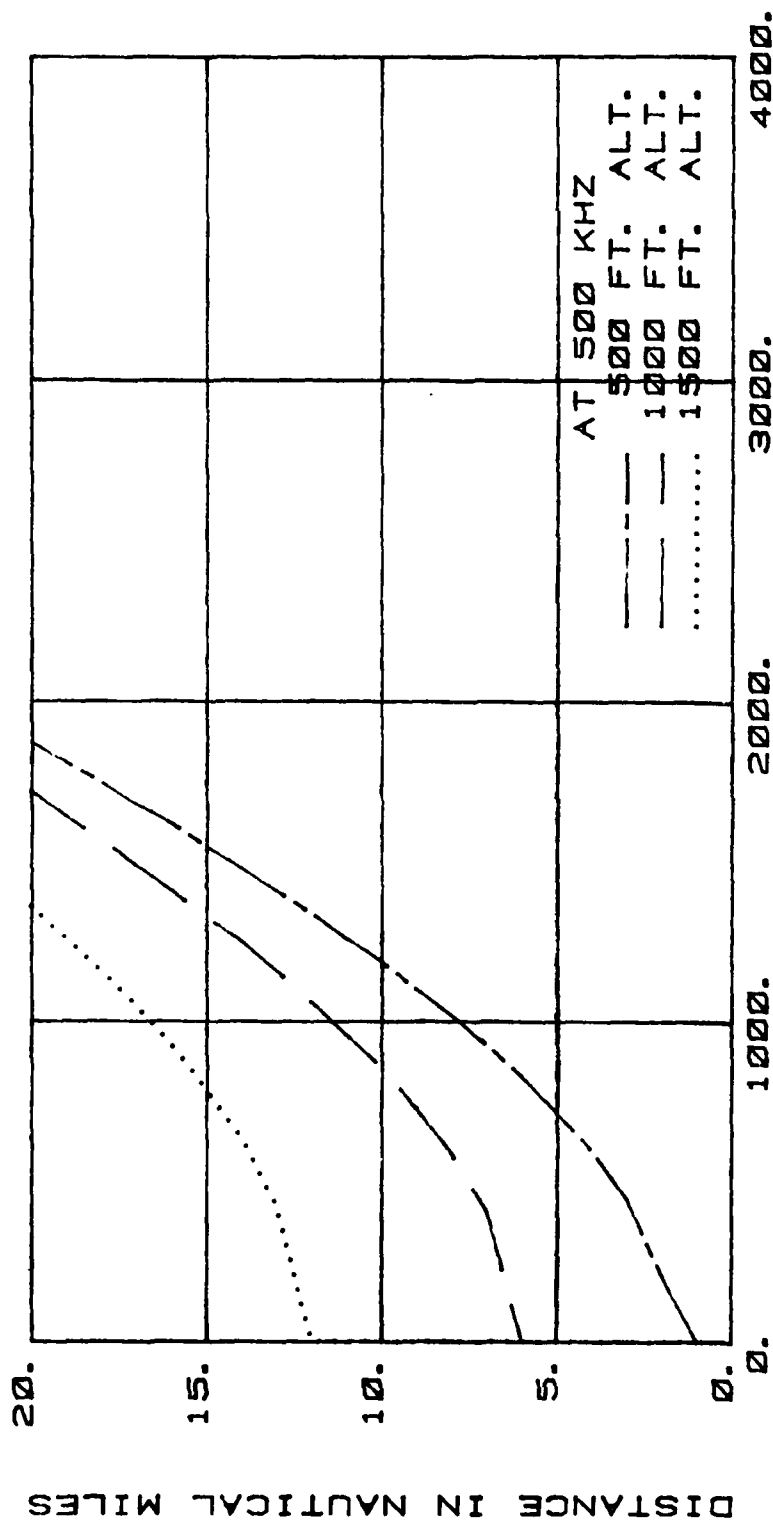


Fig. 2.14a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 500 kV, $f = 200$ kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.14b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 500 kV, $f = 500$ kHz, under heavy rain condition.

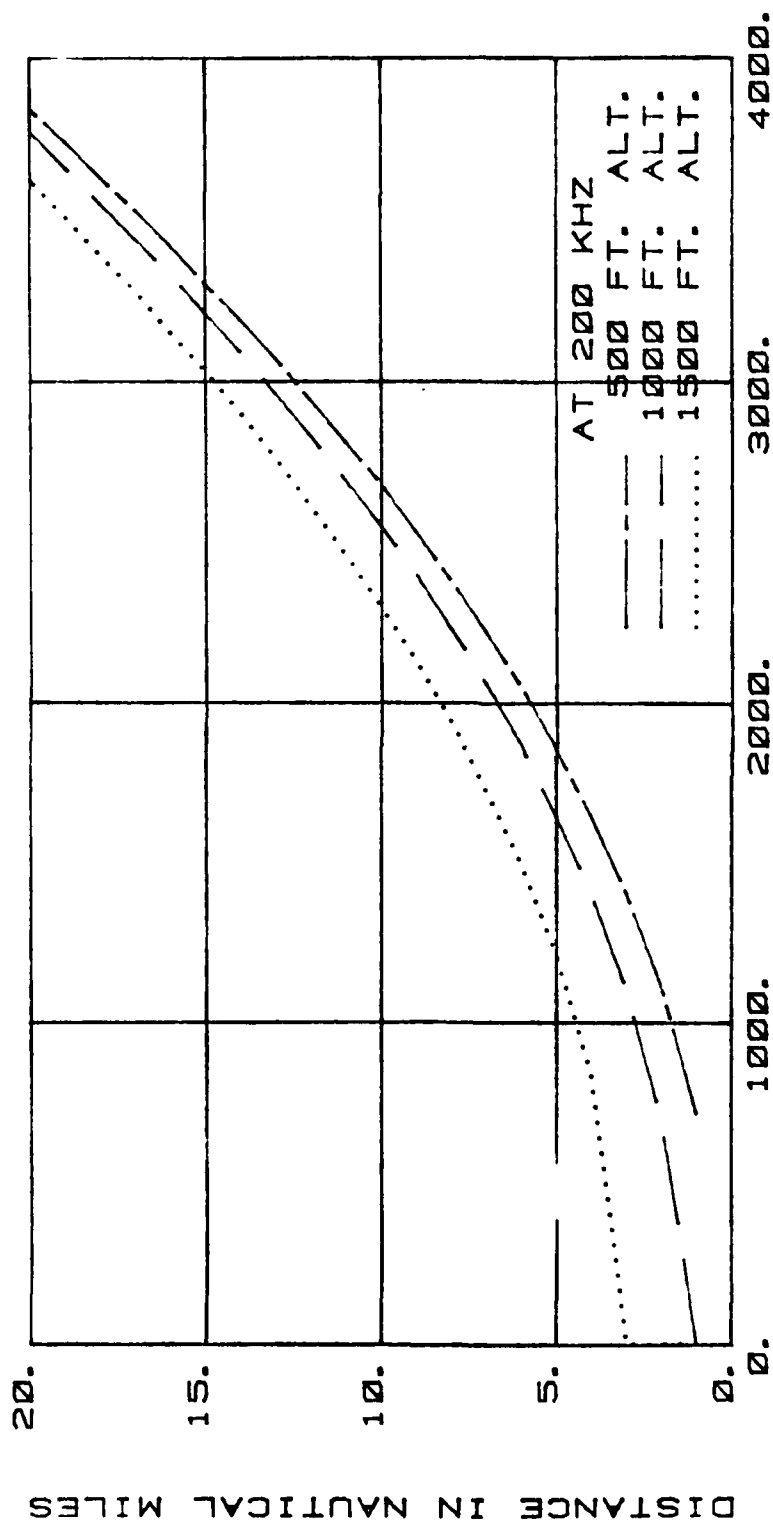


Fig. 2.15a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 765 kV, $f = 200$ kHz, under heavy rain condition.

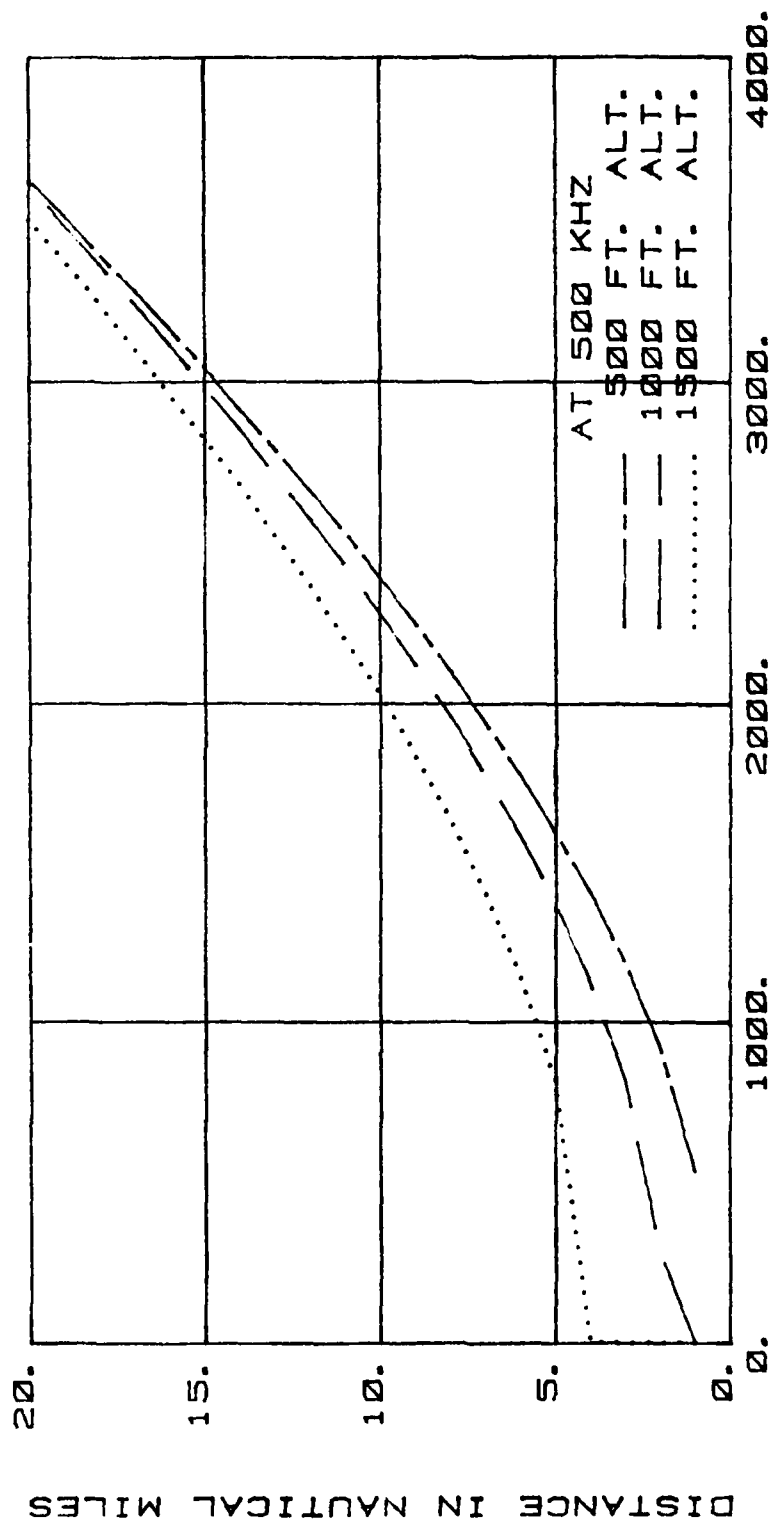


Fig. 2.15b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 765 kV, $f = 500$ kHz, under heavy rain condition.

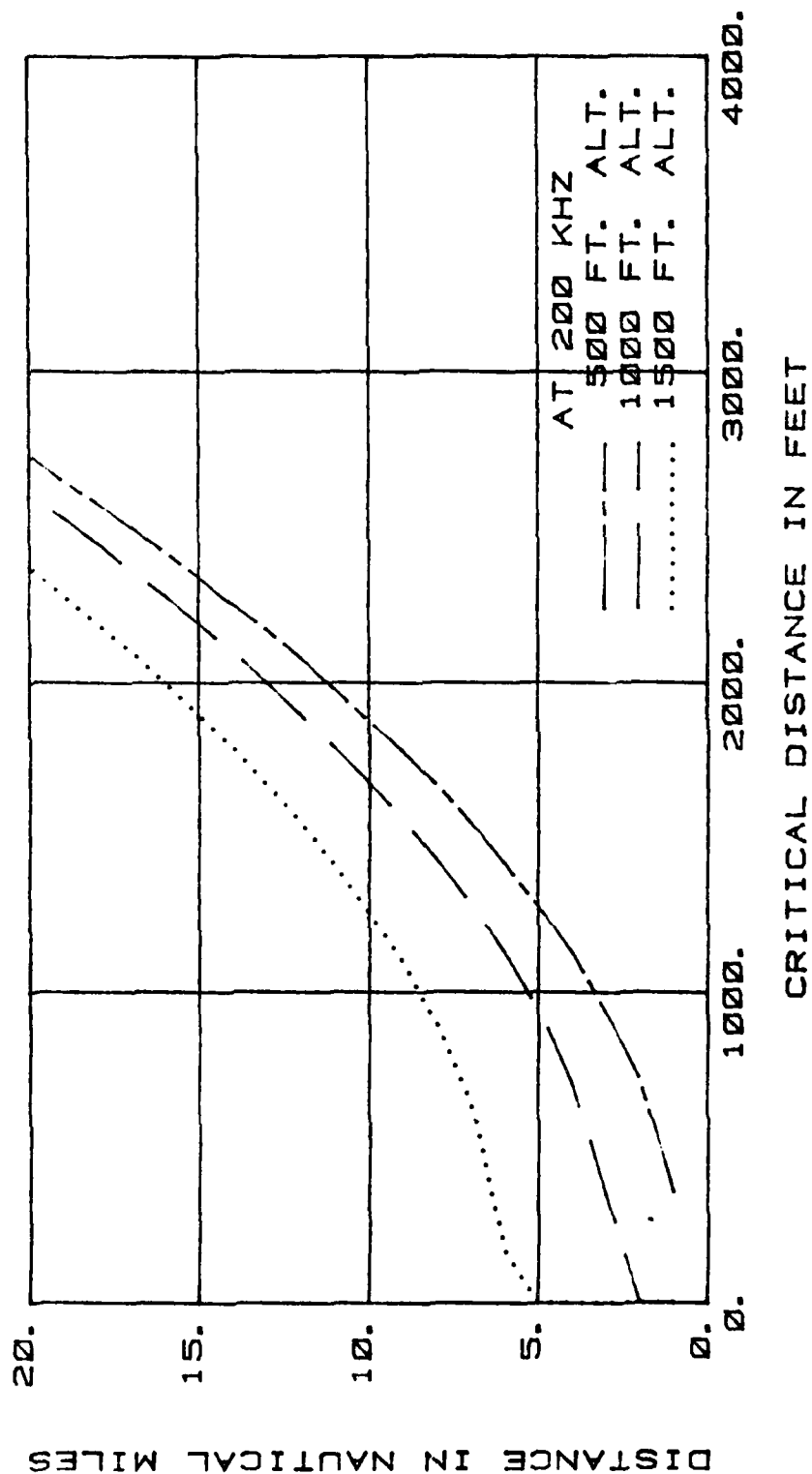
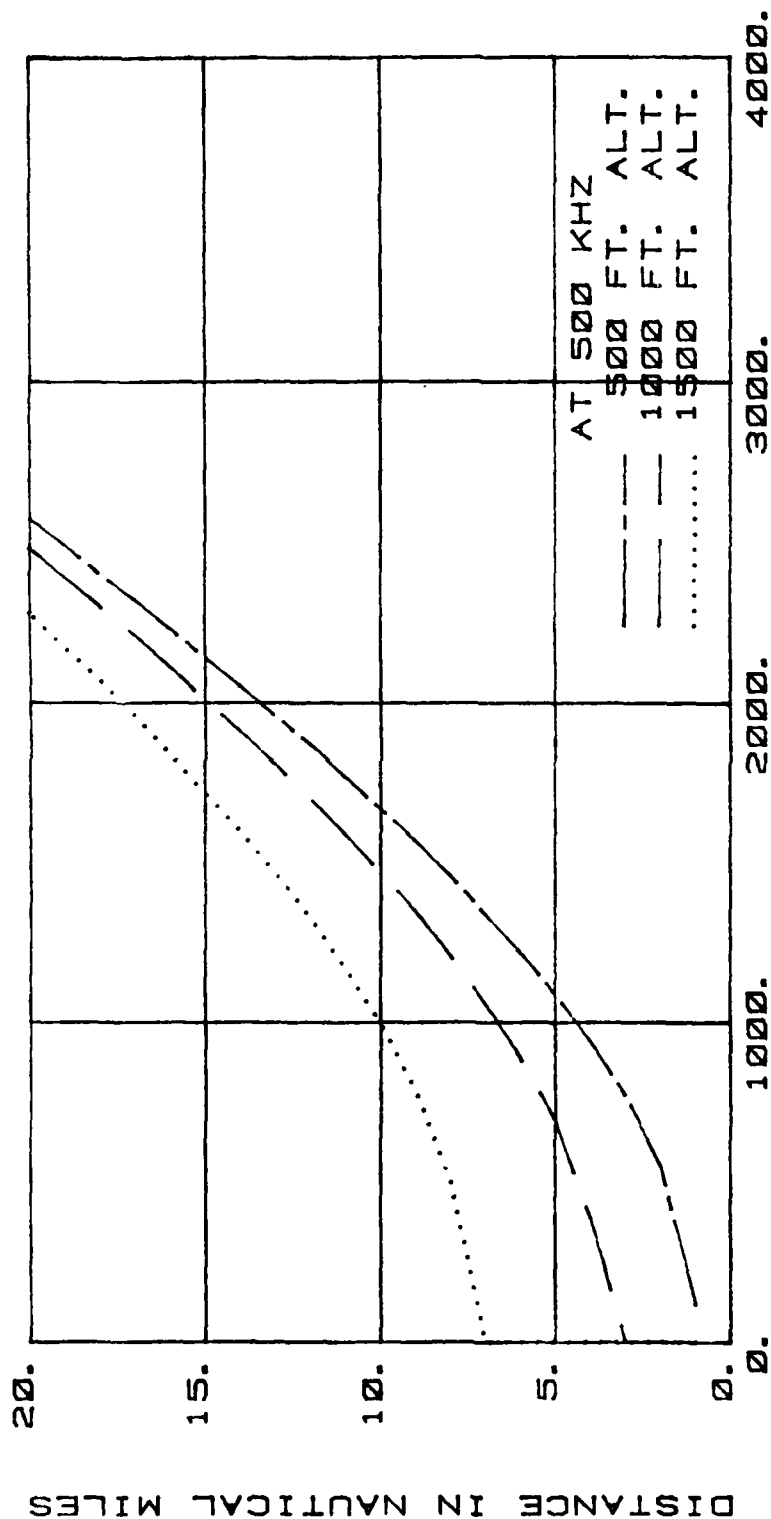


Fig. 2.16a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 1100 kV, $f = 200$ kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.16b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 1100 kV, $f = 500$ kHz, under heavy rain condition.

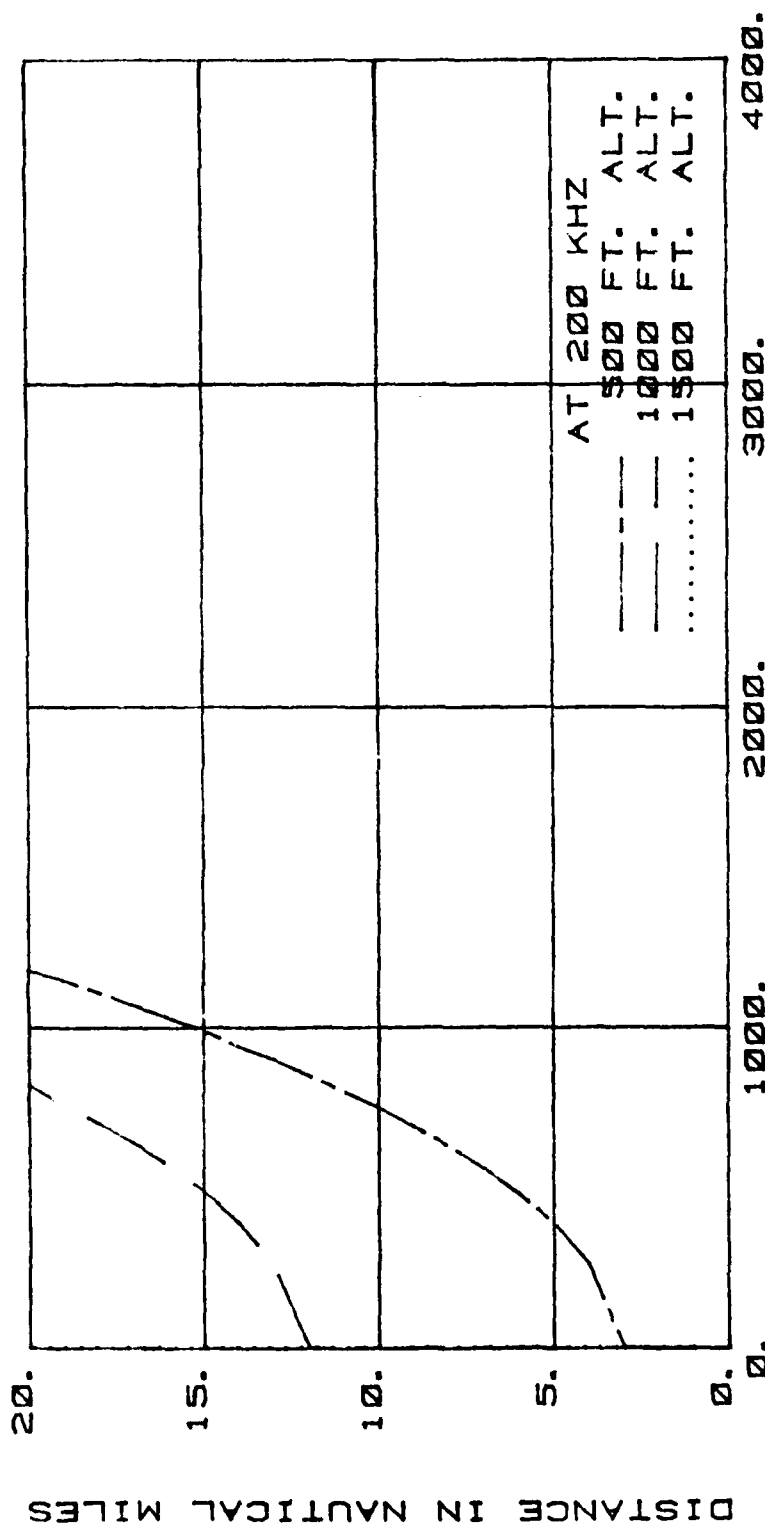


Fig. 2.17a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 345 kv, $f = 200$ kHz, under heavy rain condition.

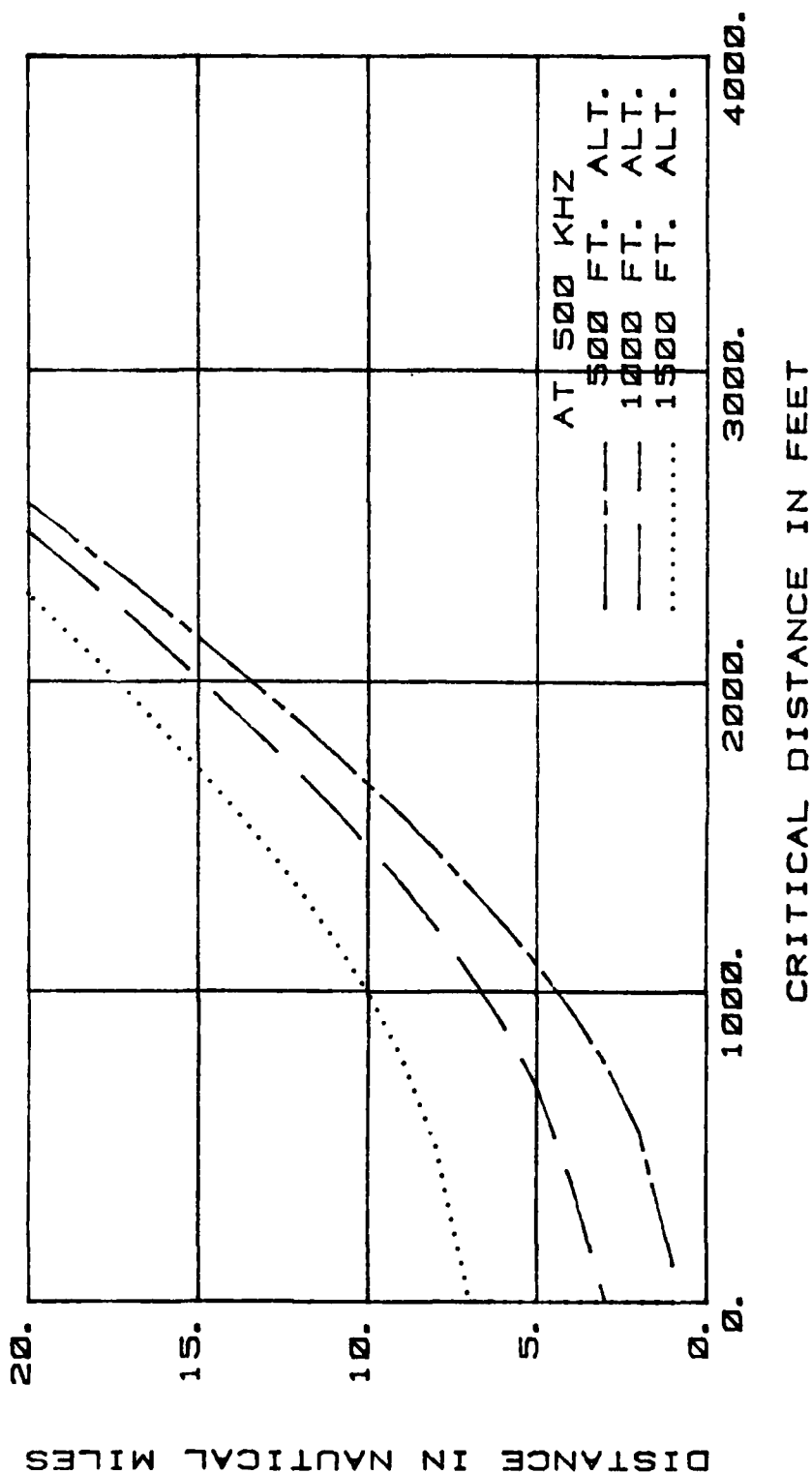


Fig. 2.16b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 1100 kV, $f = 500$ kHz, under heavy rain condition.

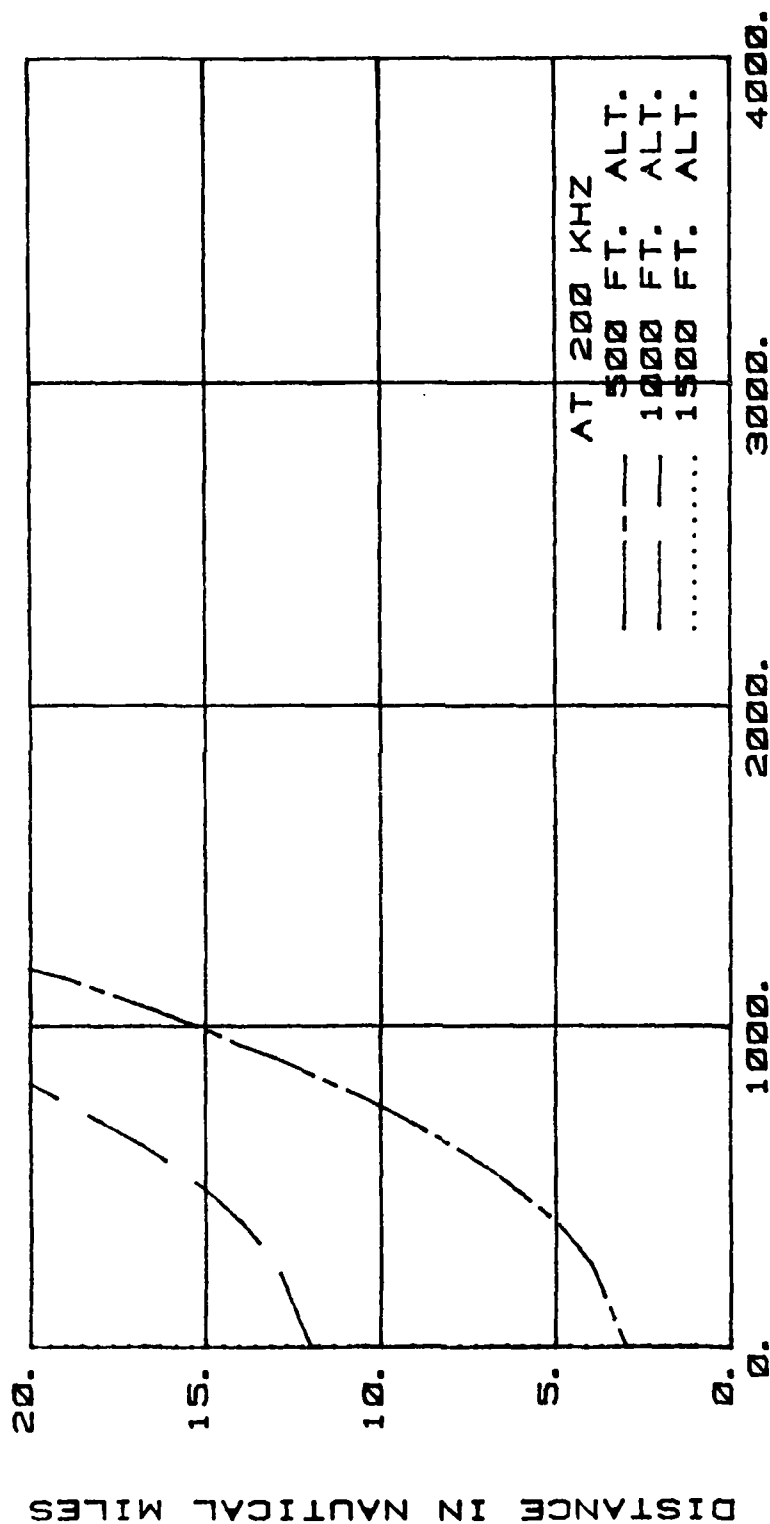


Fig. 2.17a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 345 kV, $f = 200$ kHz, under heavy rain condition.

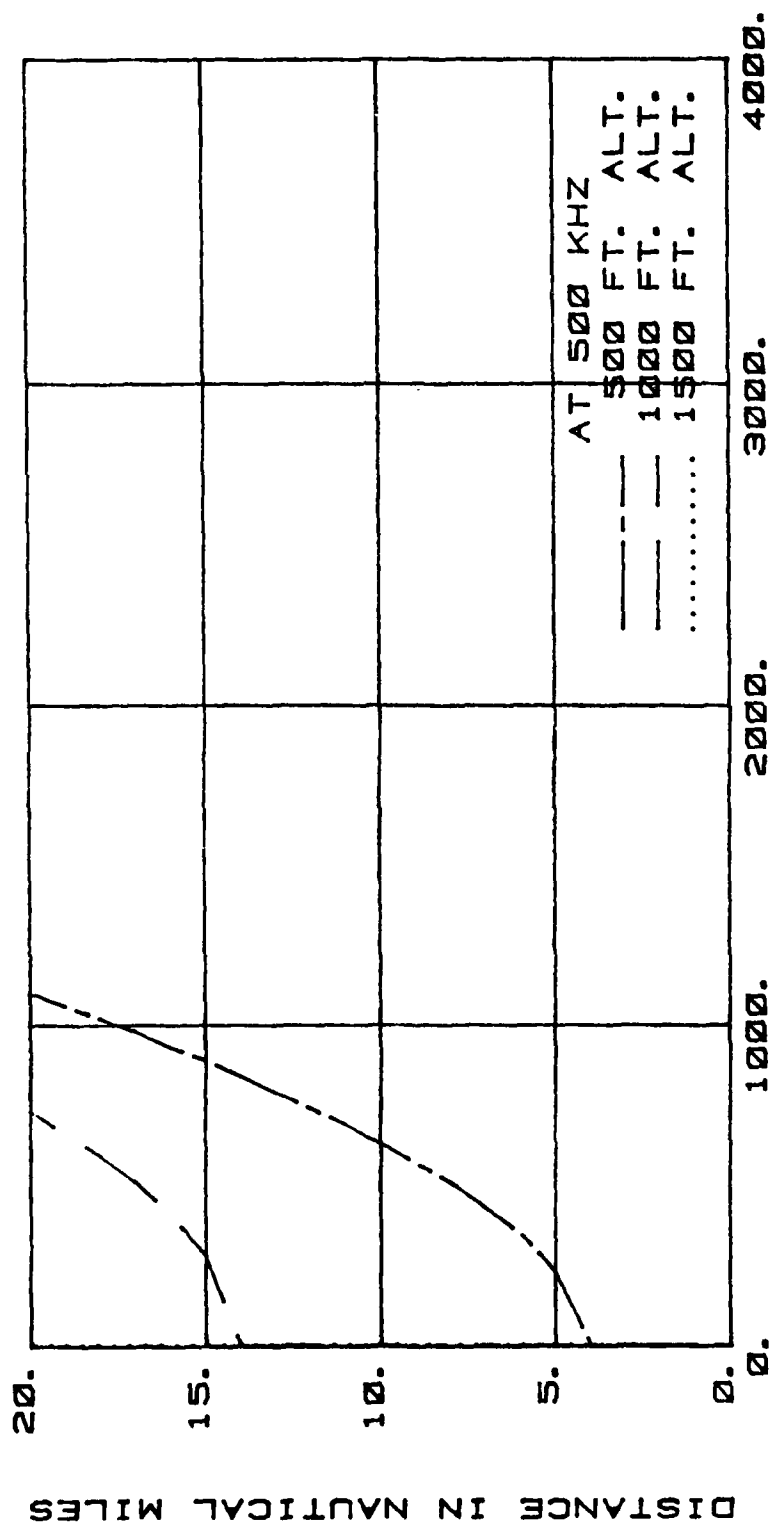


Fig. 2.17b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 345 kV, $f = 500$ kHz, under heavy rain condition.

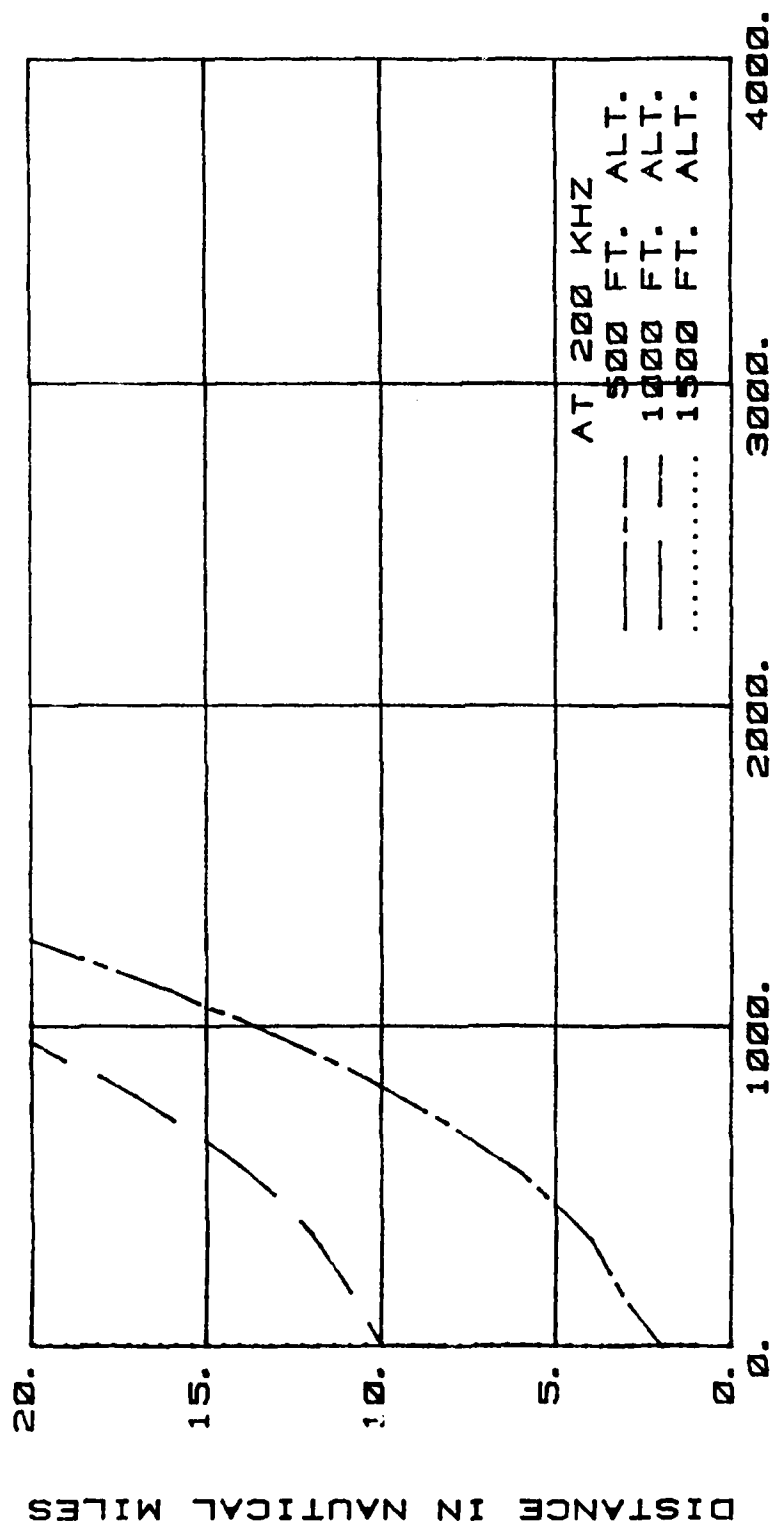
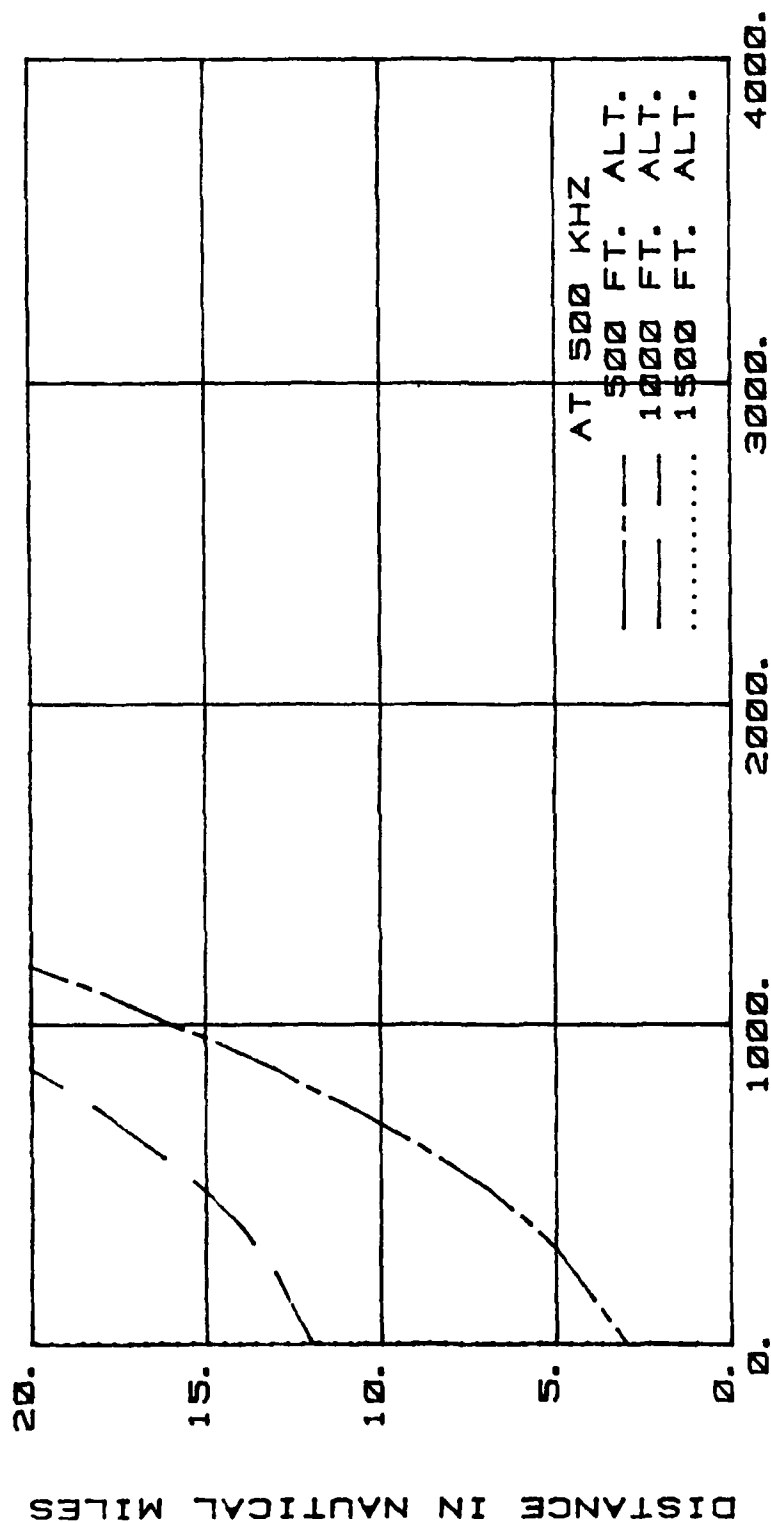
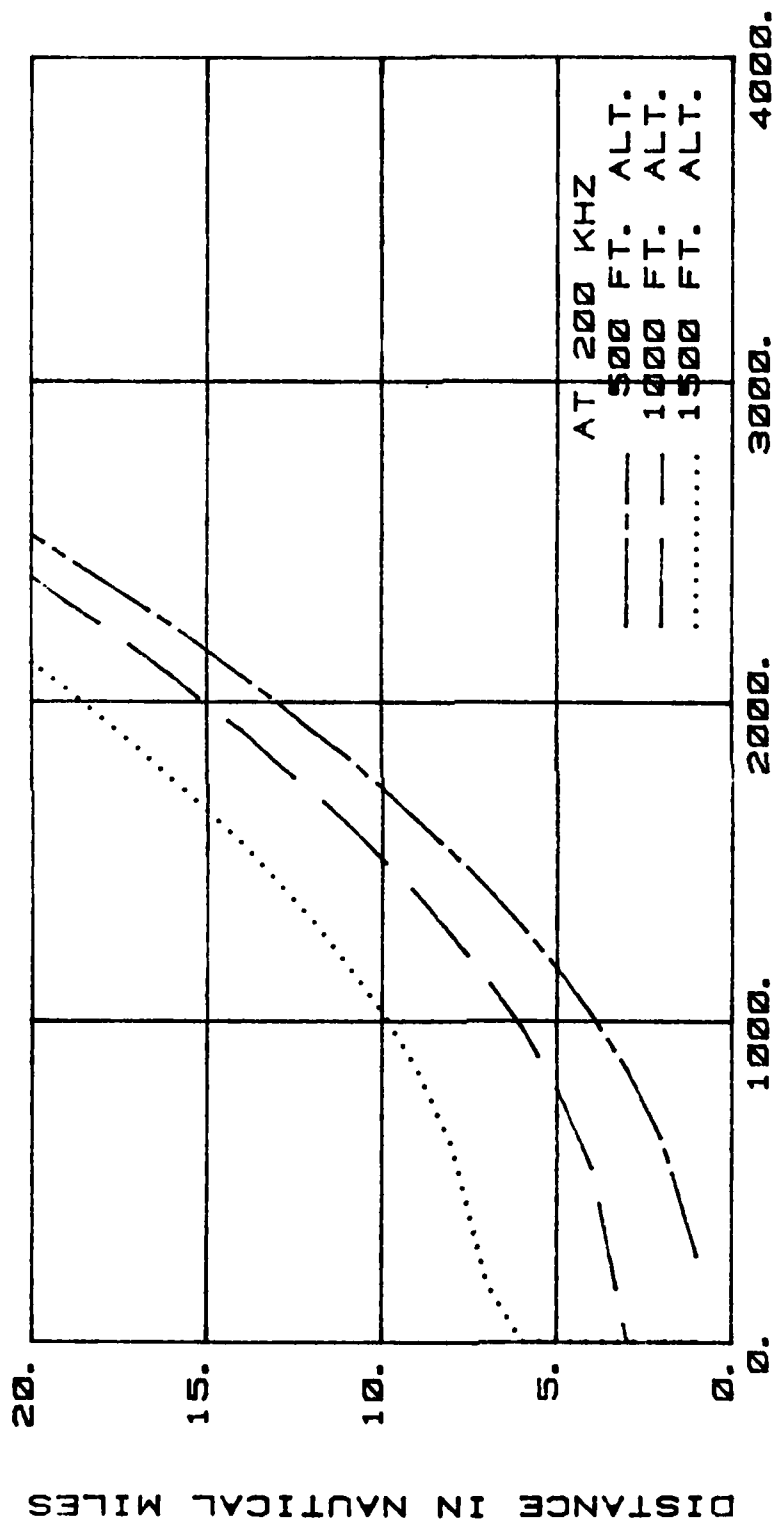


Fig. 2.18a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 500 kV, $f = 200$ kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.18b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 500 kV, $f = 500$ kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.19a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 765 kV, $f = 200$ kHz, under heavy rain condition.

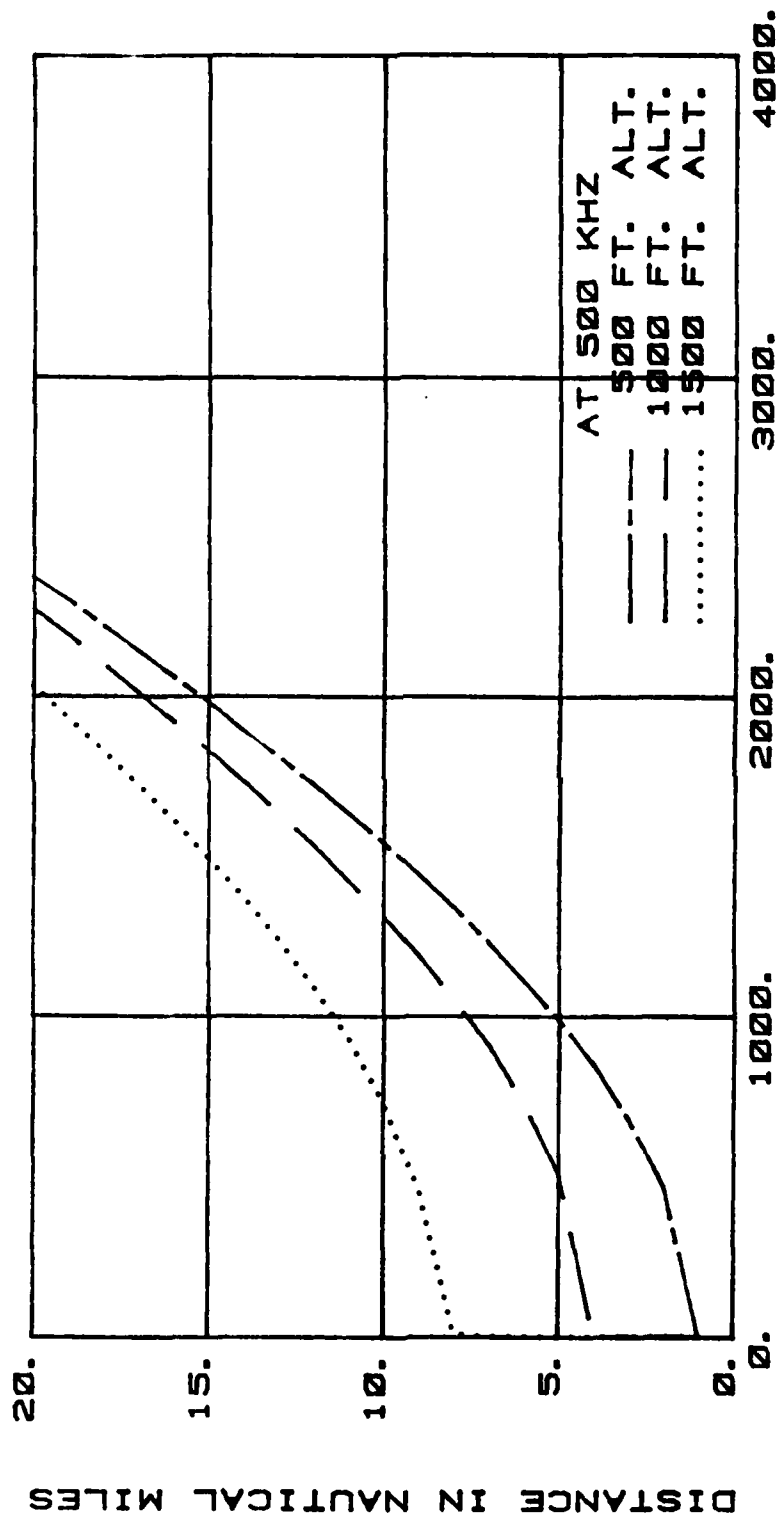


Fig. 2.19b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 765 kV, f = 500 kHz, under heavy rain condition.

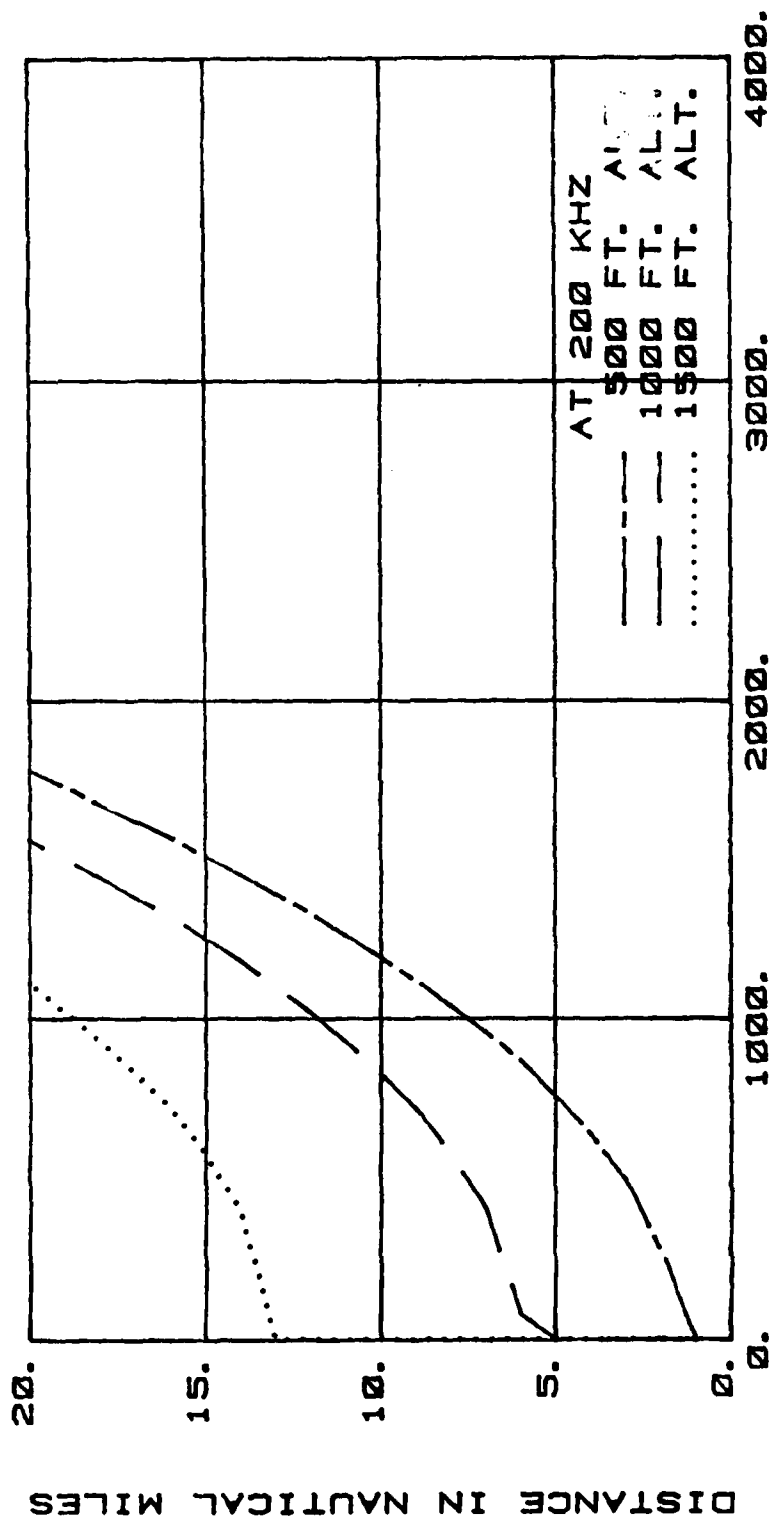


Fig. 2.20a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 1100 kV, $f = 200$ kHz, under heavy rain condition.

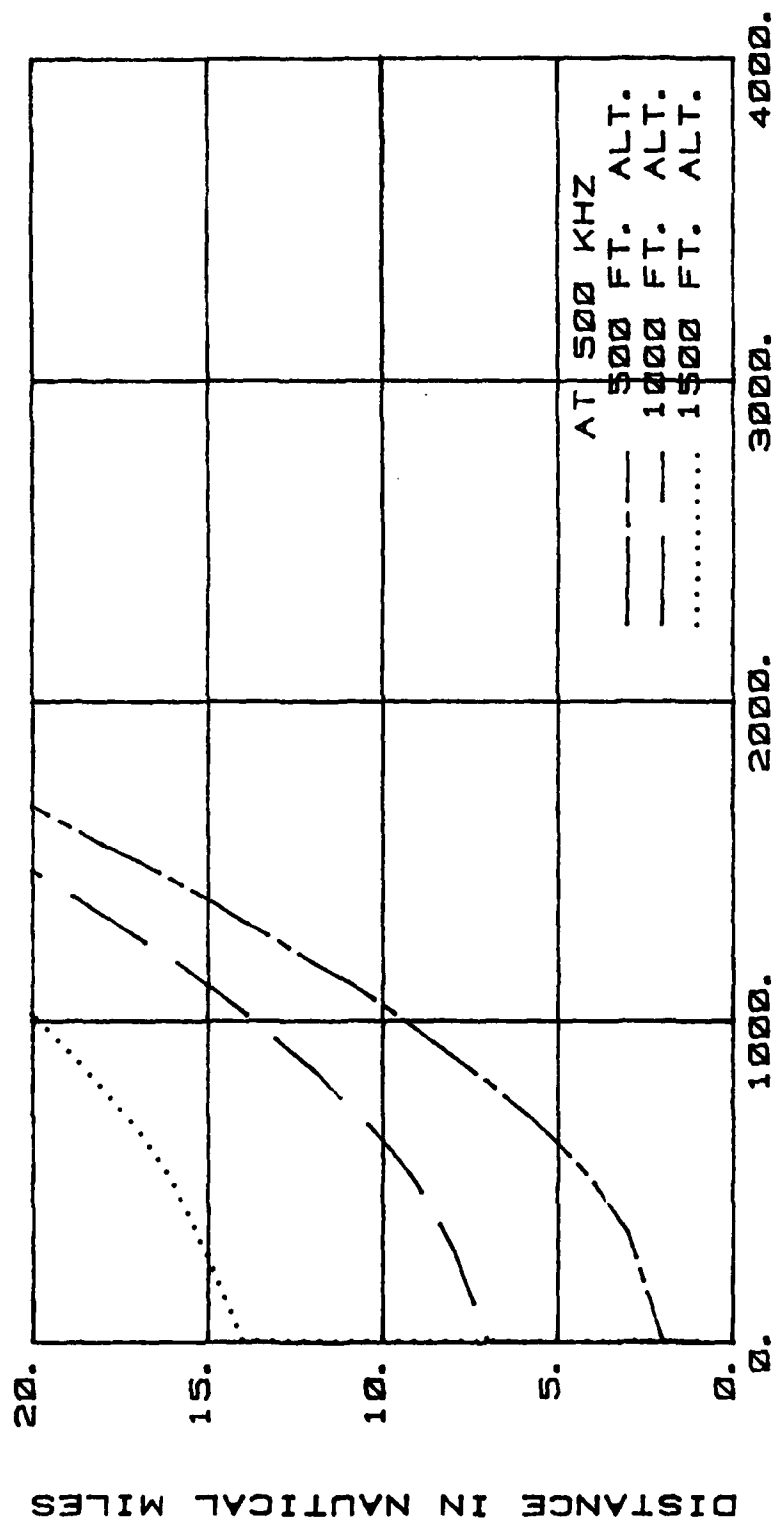


Fig. 2.20b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 1100 kV, $f = 500$ kHz, under heavy rain condition.

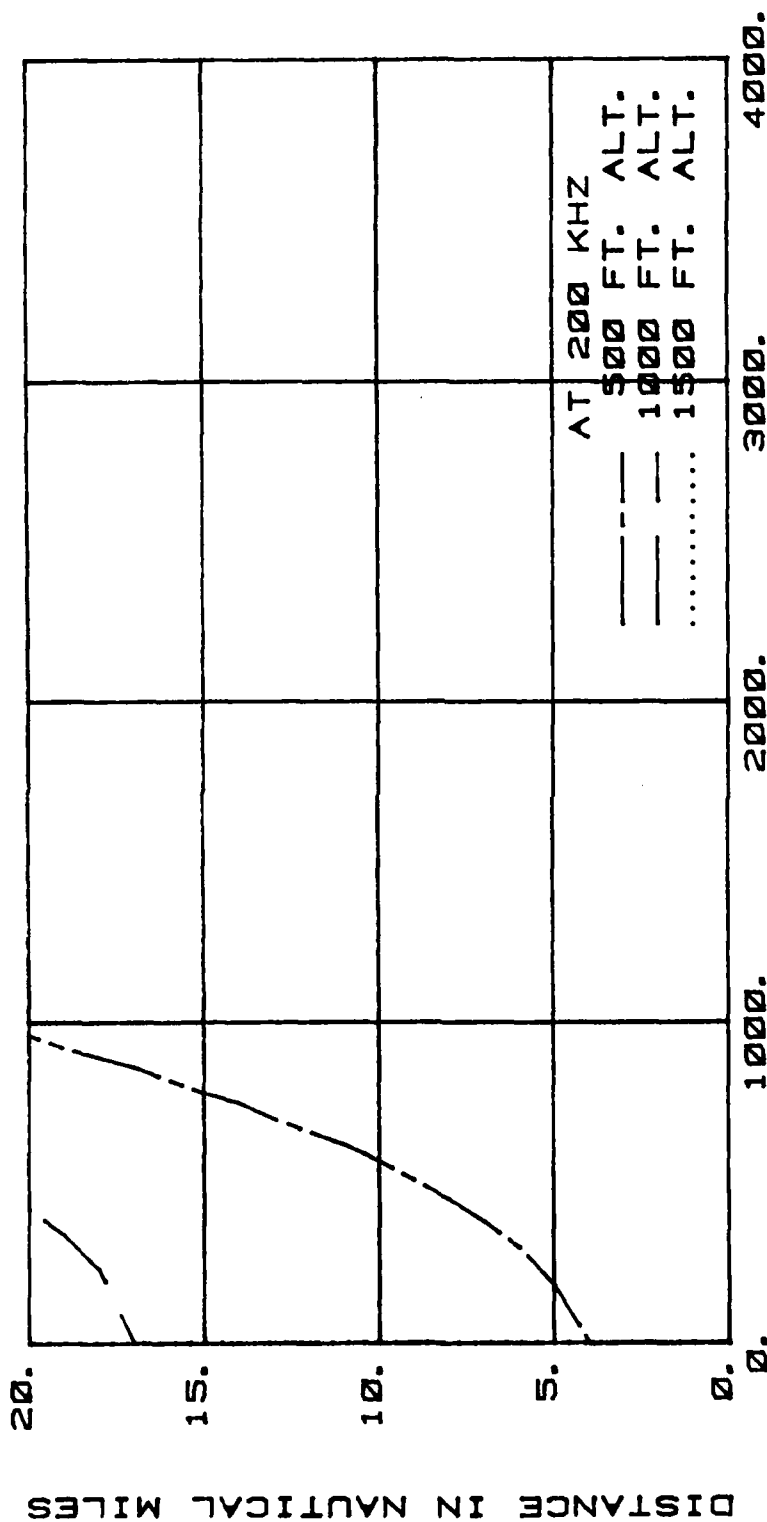
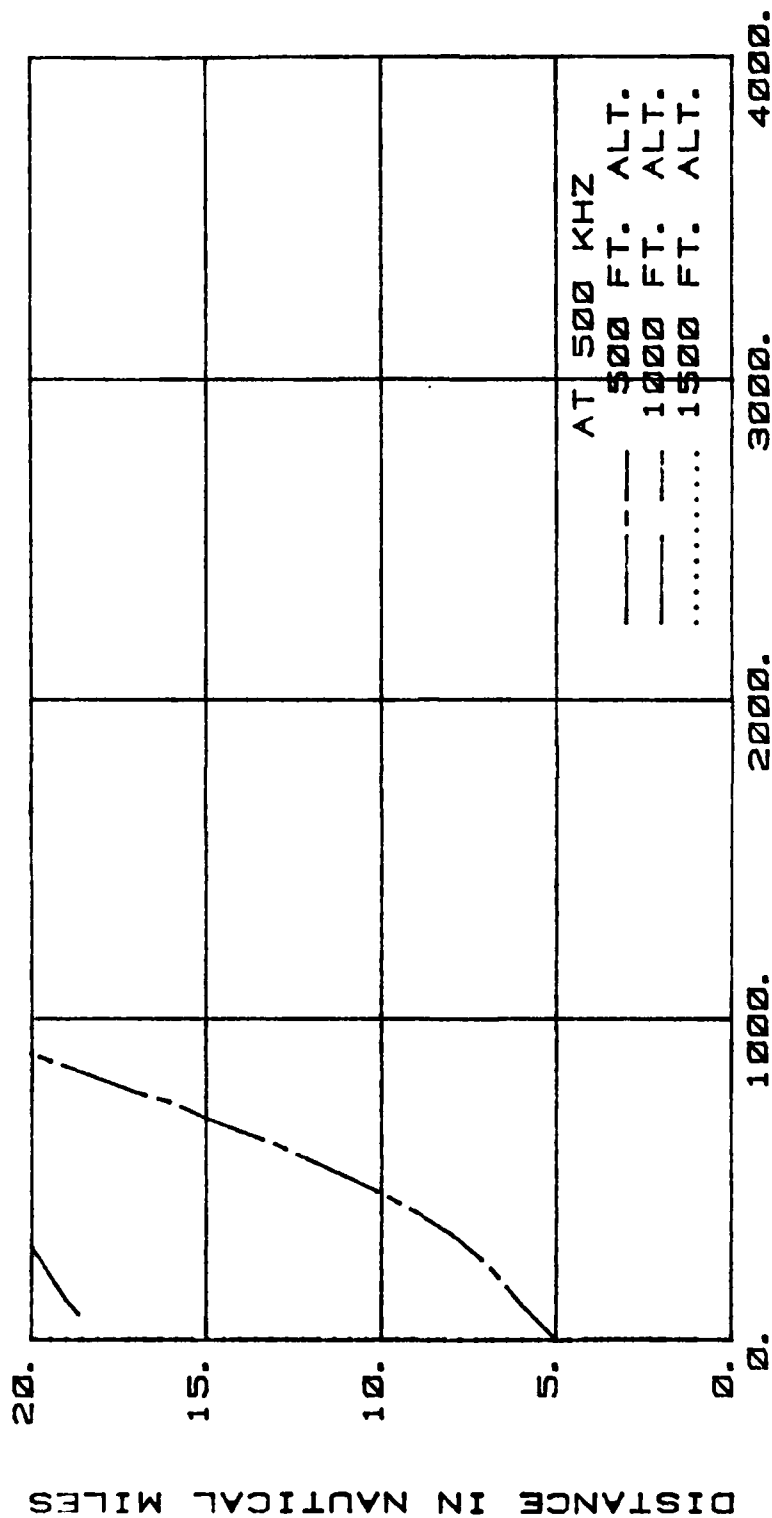
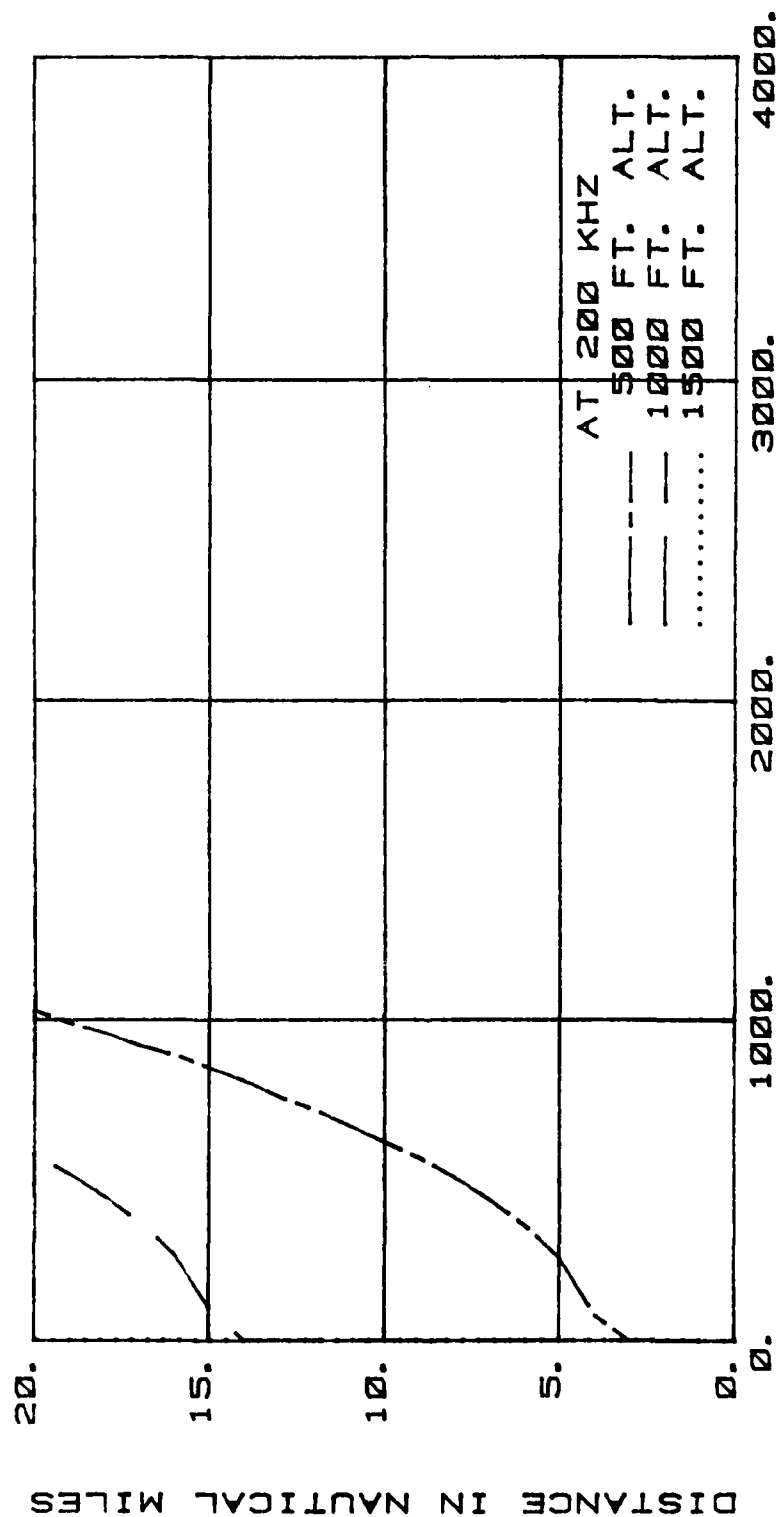


Fig. 2.21a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 345 kV, $f = 200$ kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.21b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 345 kV, $f = 500$ kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.22a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 500 kV, $f = 200$ kHz, under heavy rain condition.

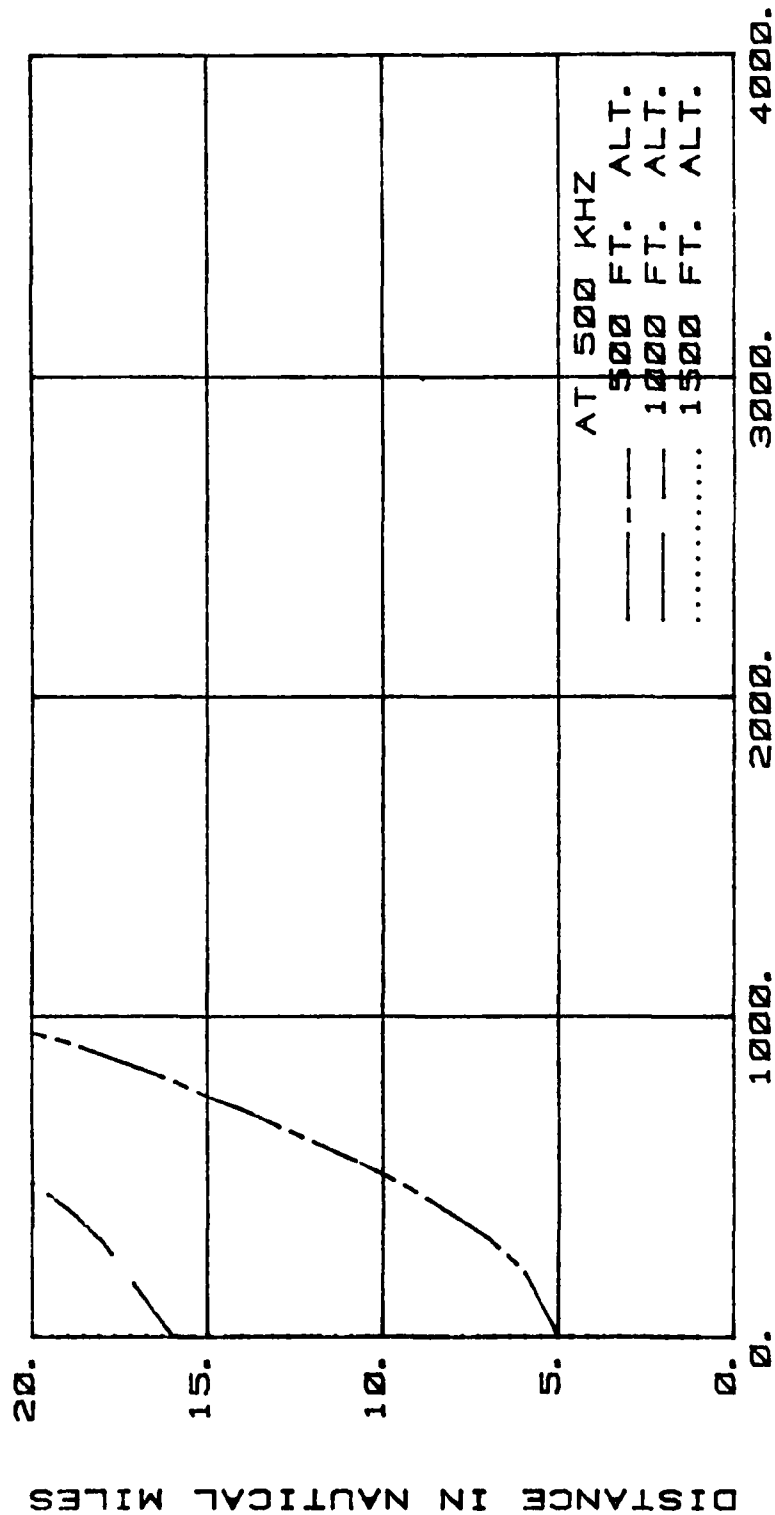


Fig. 2.22b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 500 kV, $f = 500$ kHz, under heavy rain condition.

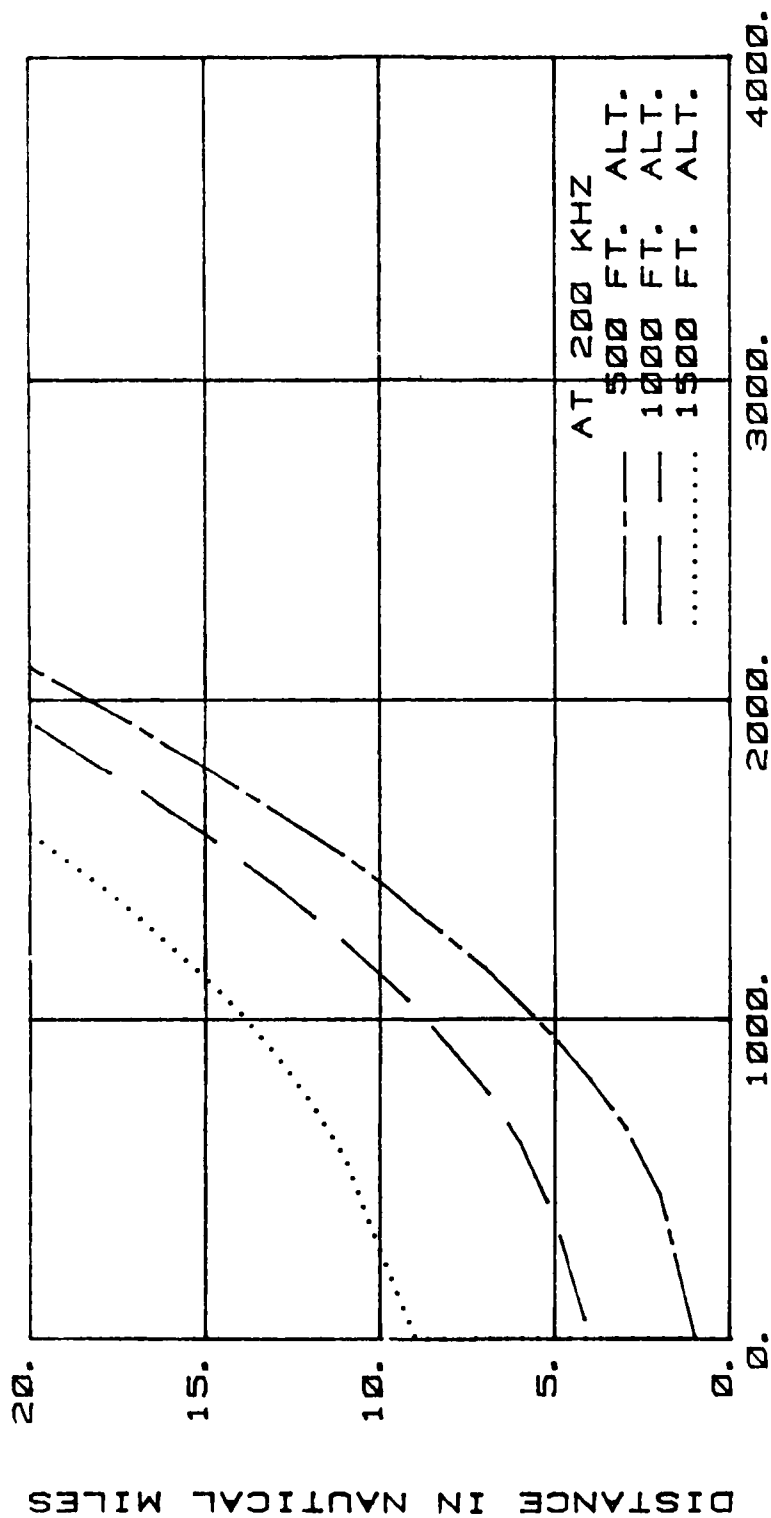


Fig. 2.23a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 765 kV, $f = 300$ Hz, after heavy rain condition.

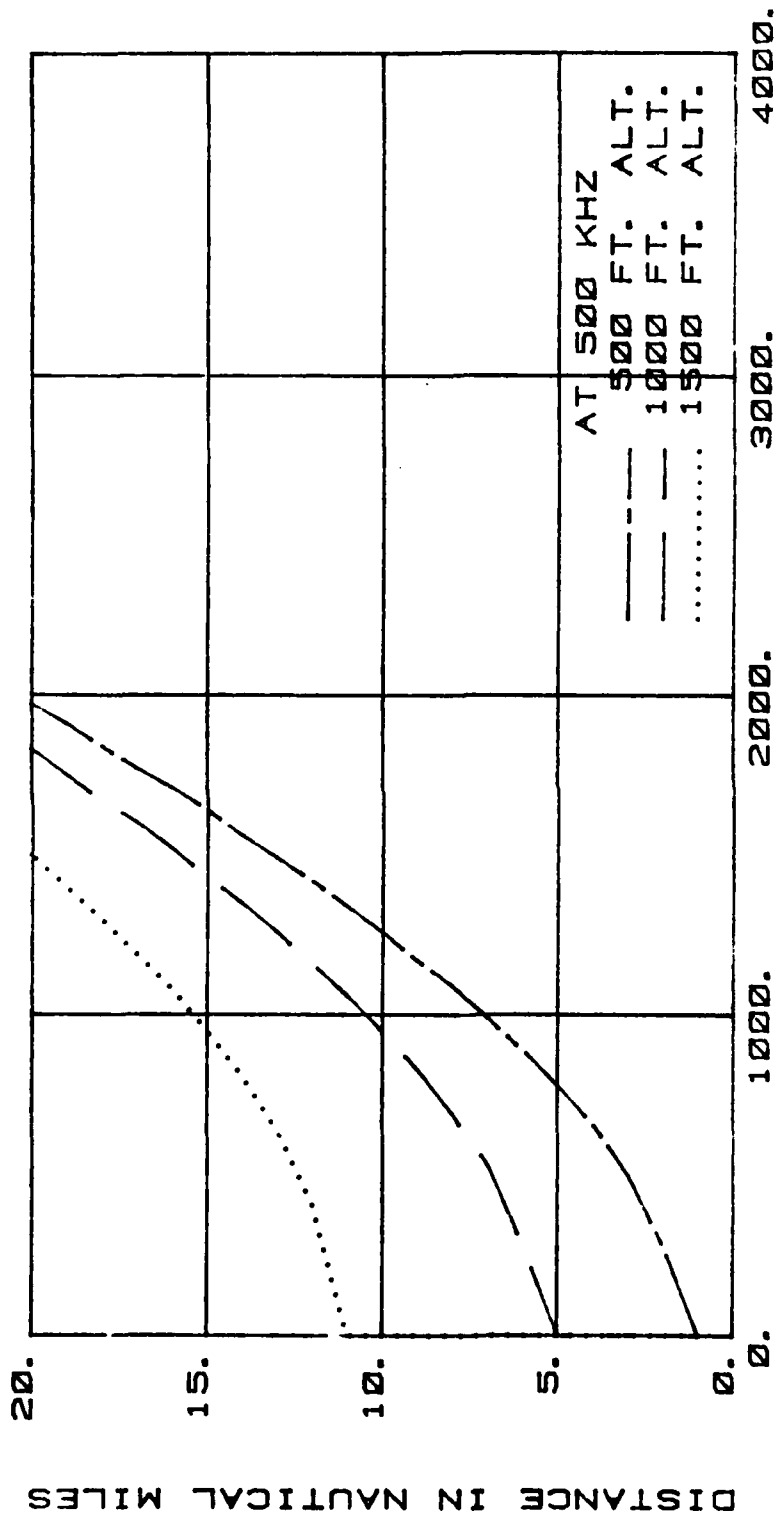
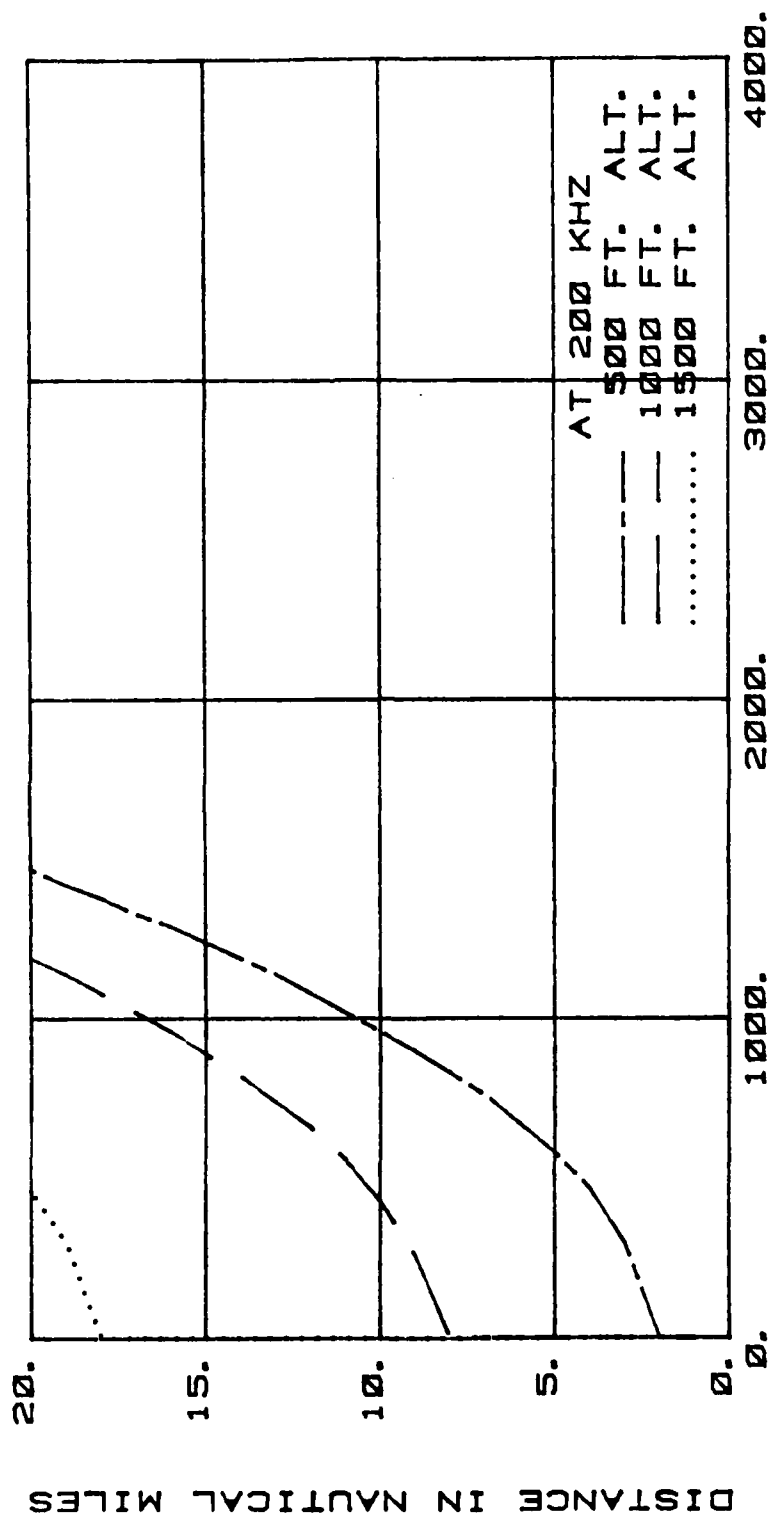


Fig. 2.23b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 765 kV, $f = 500$ kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.24a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 1100 kV, $f = 200$ kHz under heavy rain condition.

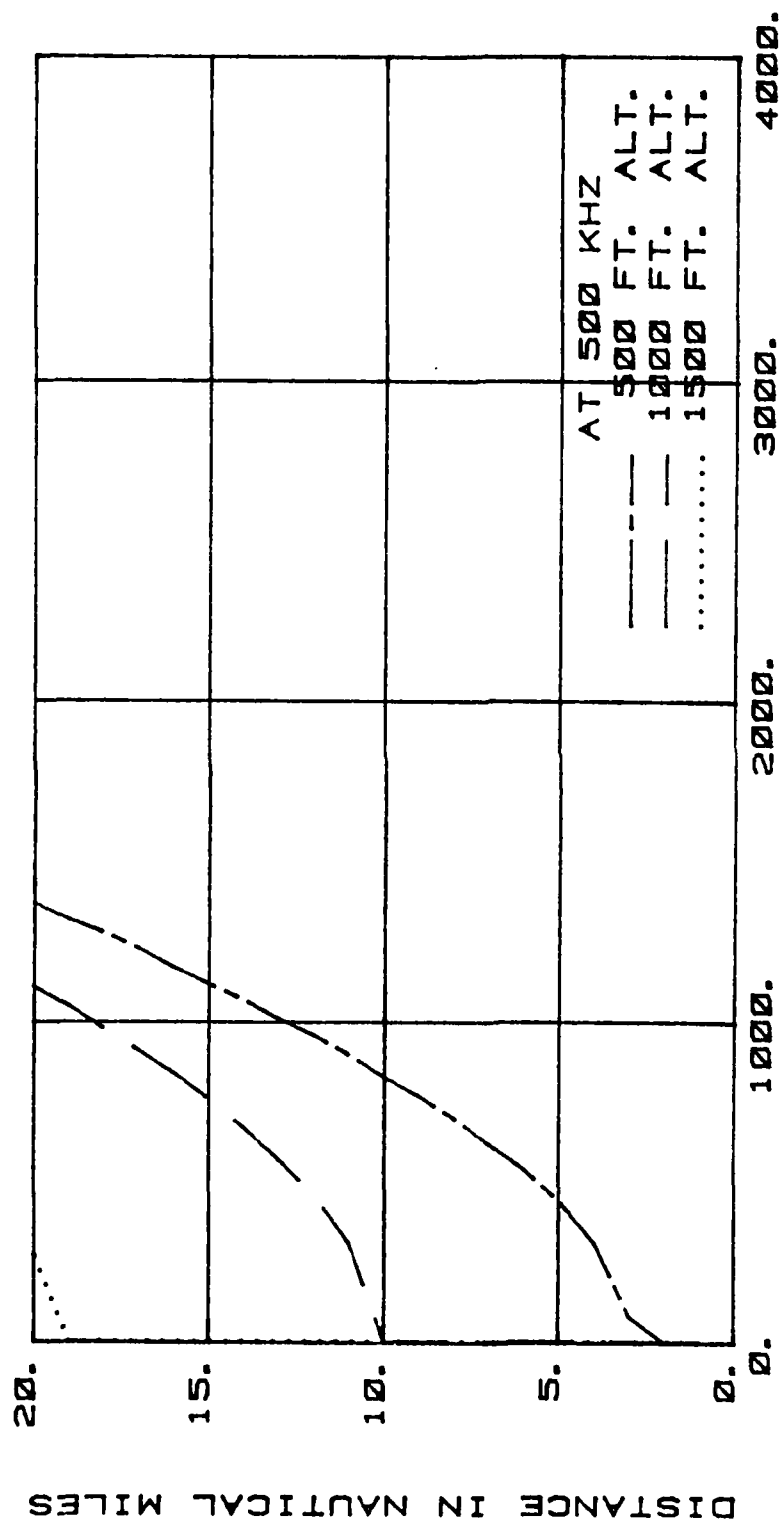


Fig. 2.24b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 1100 kV, $f = 500$ kHz, under heavy rain condition.

Chapter III

PREDICTION OF RADIO INTERFERENCE NOISE FROM DC POWERLINES

3.1 Introduction

Direct-current powerlines can be classified into three types. They are: 1) the monopolar link, 2) the bipolar link and 3) the homopolar link.

- 1) The monopolar link has one conductor, usually of negative polarity, and ground or sea return.
- 2) The bipolar link has two conductors, one positive and the other negative.
- 3) The homopolar link has two or more conductors all having the same polarity, usually negative, and always operates with a ground return.

RI noise from DC powerlines, like its counterpart in AC powerlines, is also caused by corona discharges on the line conductors. Studies and reports^{12,13,14} have consistently shown that the major source of RI noise is from the positive conductor and that contribution from the negative conductor to the total RI noise is practically negligible. Based on the conclusion, the prediction method outlined here for the RI noise from the DC powerlines will only consider the bipolar link.

As opposed to RI noise from AC powerlines, RI noise from DC powerlines decreased under heavy rain conditions. The above mentioned studies and reports have concluded that under foul and wet weather conditions, the RI noise level decreased considerably. However, the RI noise level increases under fair weather conditions.

Another result of the investigations is that there is a large

effect of wind velocity on the level of RI noise. The EPRI test¹² concludes that the RI noise levels are increased by wind, with the greatest influence being when the direction of air flow is from negative to positive conductors. A wind velocity of 15 meter/second (33.3 mph) will cause an increament of about 5 dB/ μ V/m. Another report¹³ concludes that the attenuation of the RI noise level laterally from the positive conductor is not appreciably affected by conductor configuration or pole spacing.

3.2 Computation of RI Noise from DC Powerlines

To date, there are only two empirical formula developed for the calculation of RI noise from DC powerlines. One has been developed by EPRI and the other by Reiner and Gehrig¹⁴. Since EPRI is the authority on this subject matter, we will use their equation for the prediction of RI noise from DC powerlines.

The RI noise level can be calculated by

$$E = 214 \log \frac{g_{\max}}{g_0} - 278 \left(\log \frac{g_{\max}}{g_0} \right)^2 + 40 \log a \quad (3-1)$$

where: E is the RI noise level in dB/ V/m at 834 kHz and the location of the observer is at 30.5 m from the positive conductor,

g_{\max} is the maximum conductor surface gradient in kV/cm,

g_0 is the critical gradient in kV/cm,

a is the radius of subconductor in cm.

This is essentially the maximum value of the RI noise level as the equation is formulated for fair weather condition. For completeness, correction factors for frequency and radial distance are added into the above equation. Therefore, more generally

$$E = 214 \log \frac{g_{\max}}{g_0} - 278 \left(\log \frac{g_{\max}}{g_0} \right)^2 + 40 \log a + 27 \log \frac{834}{f} + 40 \log \frac{30.5}{d} \quad (3-2)$$

where f is the frequency in kilohertz,

d is the radial distance from the positive conductor in meters.

EPRI found g_0 to be approximately 14 kV/cm for the conductors tested.

This value will be used as a constant. For the value of g_{\max} , we will use the equation developed by Mangoldt¹⁵. The gradient factor for the bipolar DC powerlines is given by

$$G = \frac{1 + ((N - a) a/R)}{N a \ln \frac{2H}{R_{eq} \sqrt{\frac{(2H)^2}{S} + 1}}} \quad (3-3)$$

where G is the gradient factor in kV/cm per kV to ground,

R_{eq} is the radius of an equivalent bundle conductor, where

$$R_{eq} = (N a R^{N-1})^{1/N} \quad (3-4)$$

N is the number of subconductors in the bundle,

a is the radius of subconductor in cm,

R is the radius of the circle on which the centres of the subconductors lie with $R = (B/2)/\sin(\pi/N)$, where B is the distance between the adjacent subconductors,

H is the average height of conductors, defined as the minimum height above ground plus 1/3 of the sag,

S is the pole to pole spacing.

The maximum bundle surface gradient is thus obtained by the equation¹⁵

$$g_{\max} = G \cdot V \quad (3-5)$$

where: G is the gradient factor in kV/cm per kV to ground,

V is the line voltage to ground in kV.

EPRI has also made an observation that the RI noise levels attenuate as the square of the radial distance until it reaches an inflection point beyond which the attenuation is proportional to the radial distance. The inflection point can be approximated by the equation

$$d = \frac{\lambda}{2\pi} \quad (3-6)$$

where d is the radial distance from the positive conductor, and λ is the wavelength of the noise frequency. Beyond this point, equation (3.2) can be rewritten as

$$E = 214 \log \frac{g_{\max}}{g_o} - 278 \left(\log \frac{g_{\max}}{g_o} \right)^2 + 40 \log a + 27 \log \frac{834}{f} + 20 \log \frac{30.5}{d} \quad (3-7)$$

For illustration, some actual line designs will be considered. Table 3.1 details the line voltages and parameters. Fig. 3.1 to 3.4 show the characteristics of the calculated RI noise levels for each of the powerline designs listed in Table 3.1, at the frequencies of 200 kHz and 500 kHz with the location of the observer at various altitudes.

Line Config.	Line Voltage (\pm kV)	H(ft)	S(ft)	a (cm)	N
#1	400	63.00	34.50	3.048	1
#2	450	40.00	44.00	2.032	2
#3	600	49.87	36.75	1.525	4
#4	750	54.40	45.00	2.032	4

Table 3.1 DC line voltages and parameters considered

where: H is the average height of the conductors,

S is the spacing between the conductors,

a is the radius of the subconductors,

N is the number of subconductors in a bundle.

Appendix E details program DCRI listing for the computation of the RI noise level radiating from the DC powerlines.

3.3 Prediction of Critical Distance Where the Ratio of Desired Signal/Undesired Noise is 15 dB

Similar to Section 2.4, the desired signal is the signal from the NDB transmitter (covered in Section 2.3), and the undesired signal is the RI noise from the DC powerlines dealt with in Section 3.2. Consider the same scenario shown in Fig. 2.12 in Section 2.4.

Fig. 3.1 to 3.4 have shown that the levels of the RI noise radiated from the DC powerlines are lower than that radiated from the AC powerlines. Therefore, only line ± 400 kV which radiates highest RI noise level at higher altitudes is considered here. Fig. 3.5 and 3.6 indicate the critical distance for this line design at various receiver altitudes with the ERP of the NDB being 0.05 watt and 0.1 watt respectively.

3.4 Conclusion

As in the case of the AC powerlines, a quasi-static condition is assumed and the computation of the ratio of desired signal/undesired noise involves the magnitudes of the fields only. For illustration, Fig. 3.5 and 3.6 show the critical distances for an NDB transmitter with an ERP 0.05 watt and 0.1 watt respectively. These values of ERP are too low for any practical purposes. It can be predicted that at a higher range

of ERP values, the critical distance will reduce almost to zero. Thus if a bipolar DC powerline is located close to an NDB transmitter, the RI noise radiated by the powerline should cause no serious effect to an aircraft flying past it.

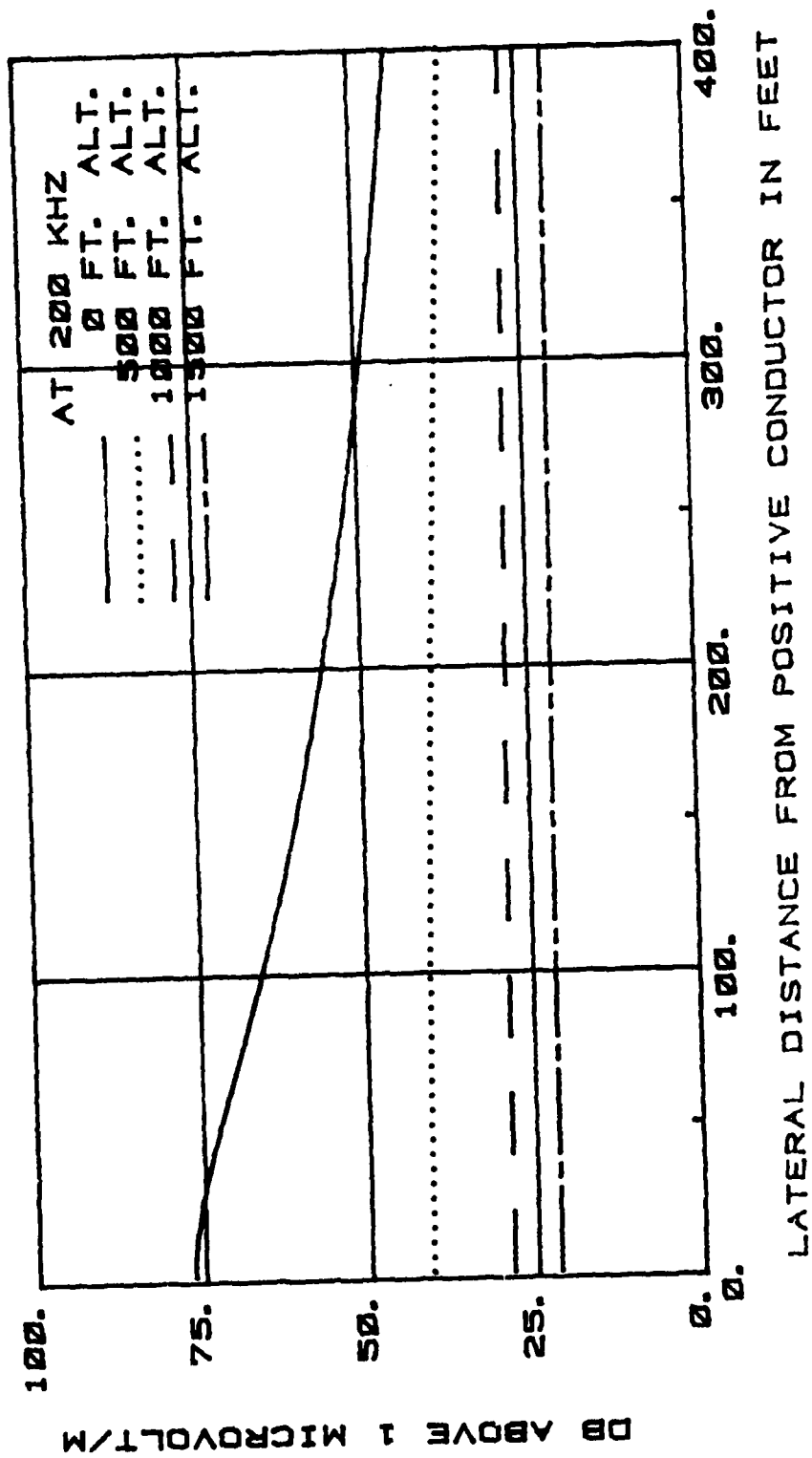


Fig. 3.1a Calculated RI noise profile for a bipolar ± 400 kV DC powerline at 200 kHz under fair weather condition.

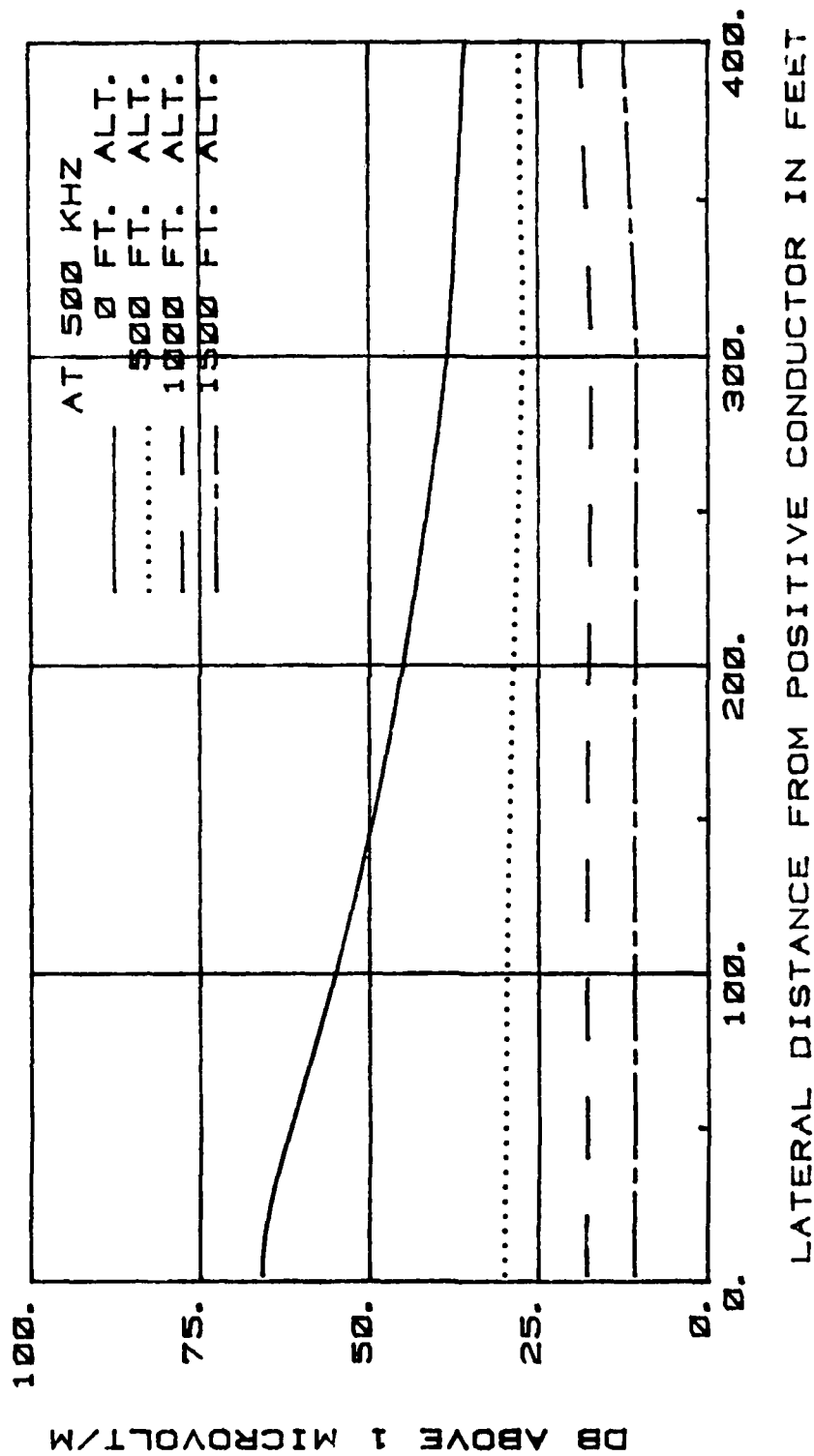


Fig. 3.1b Calculated RI noise profile for a bipolar ± 400 kV DC powerline at 500 kHz under fair weather condition.

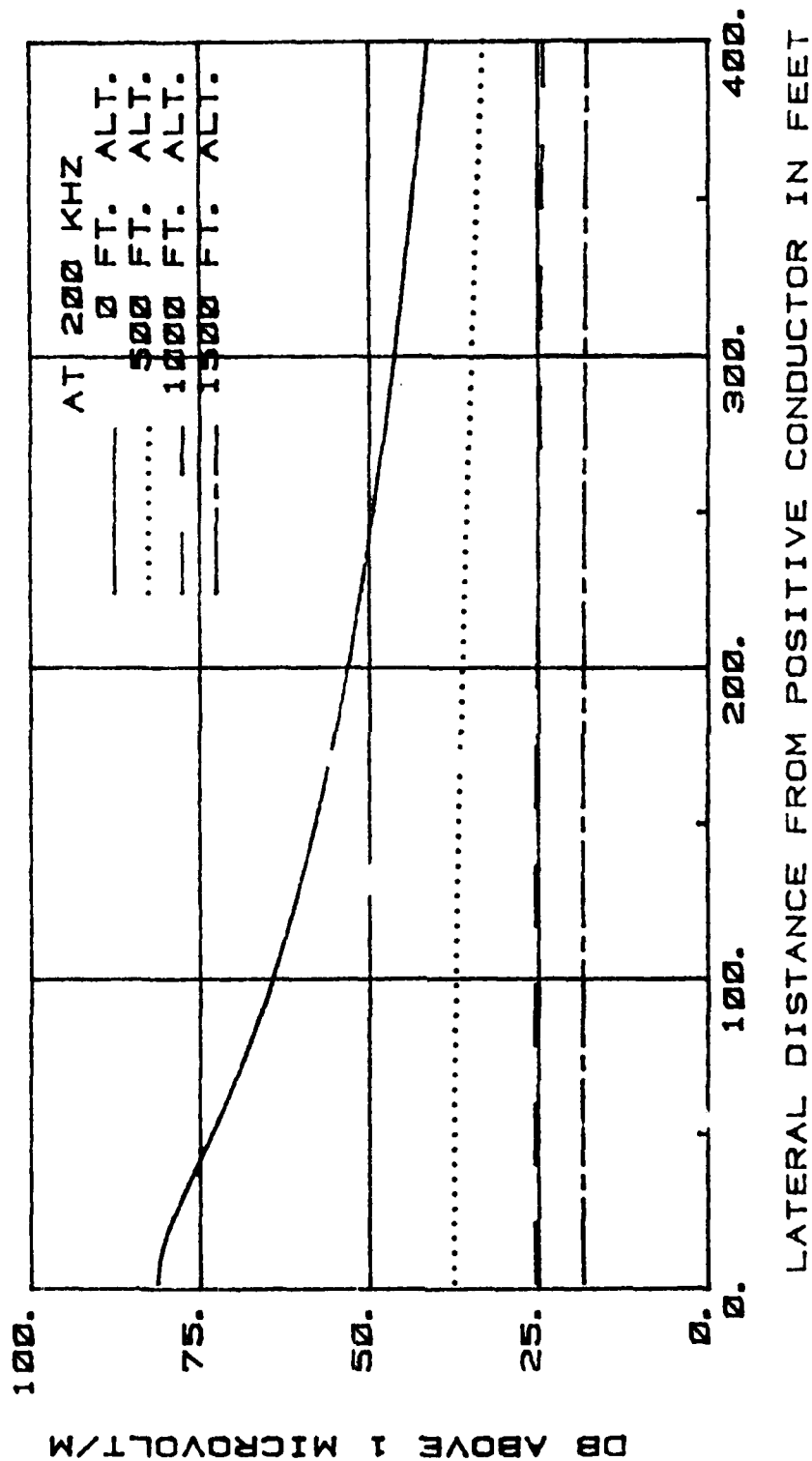


Fig. 3.2a Calculated RI noise profile for a bipolar ± 450 kv DC powerline at 200 kHz under fair weather condition.

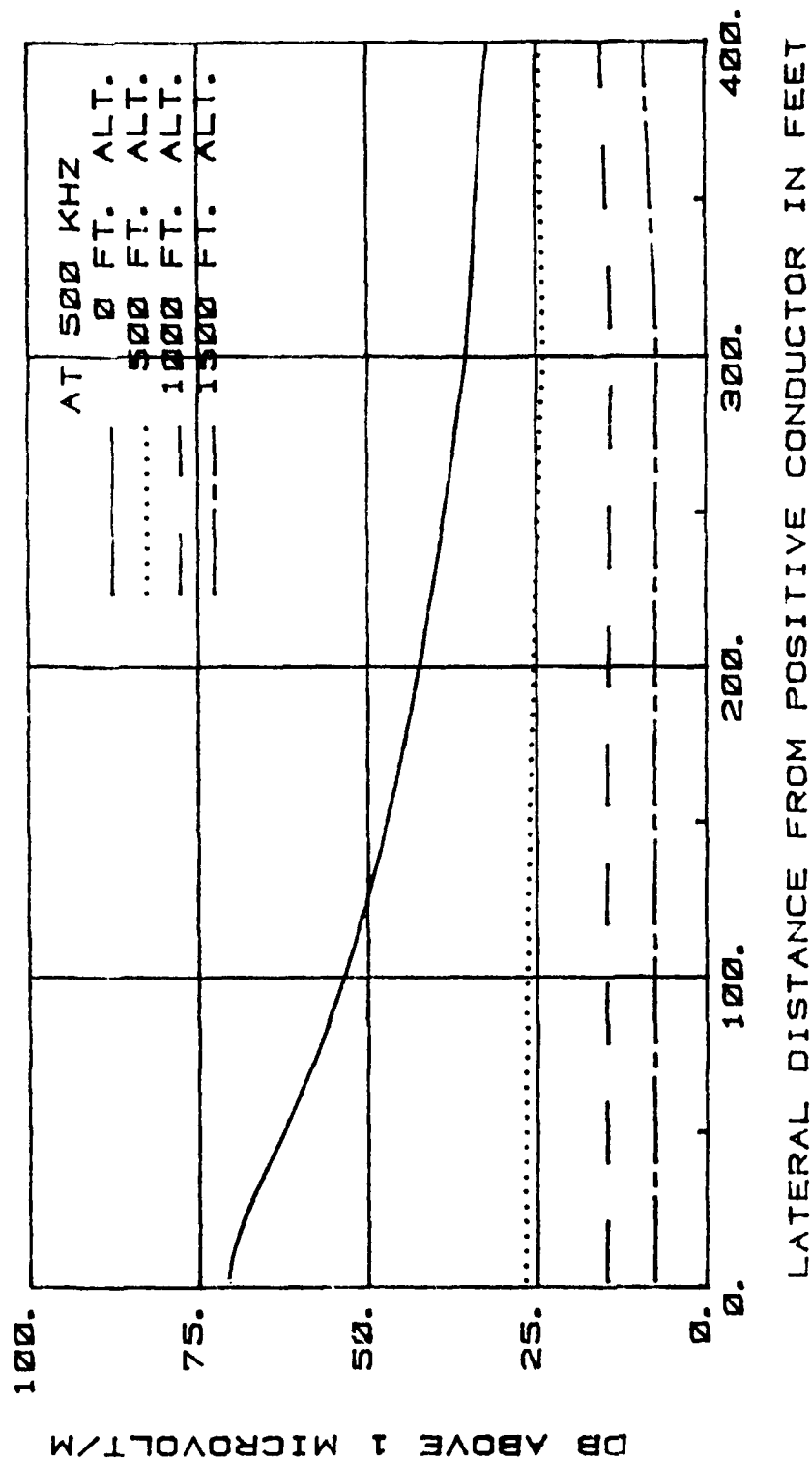


Fig. 3.2b Calculated RI noise profile for a bipolar ± 450 kV DC powerline at 500 kHz under fair weather condition.

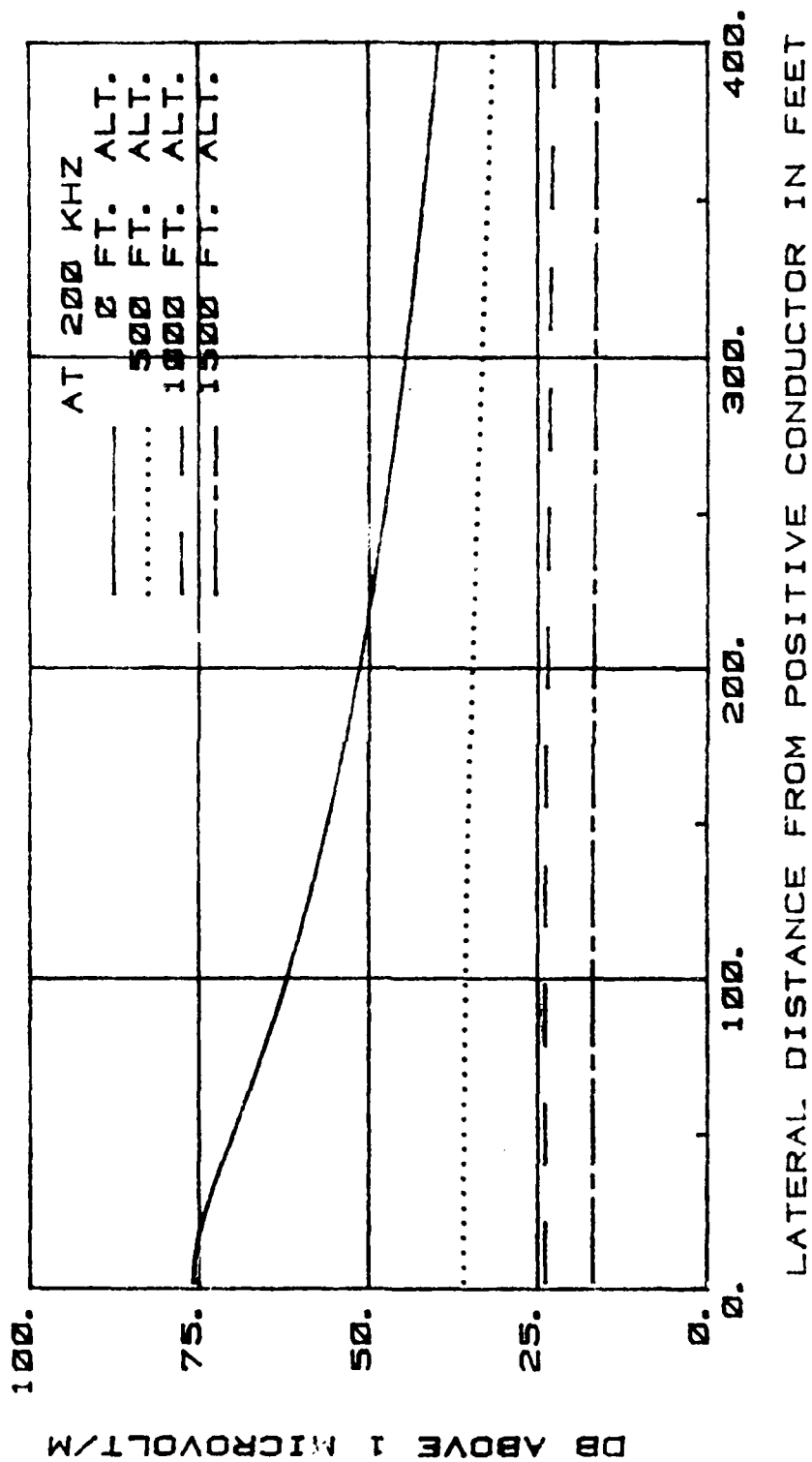


Fig. 3.3a Calculated RI noise profile for a bipolar ± 600 kV DC powerline at 200 kHz under fair weather condition.

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EFFECTS OF HIGH VOLTAGE TRANSMISSION LINES ON NON-DIRECTIONAL B-ETC(U)

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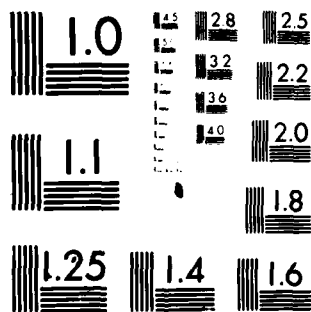
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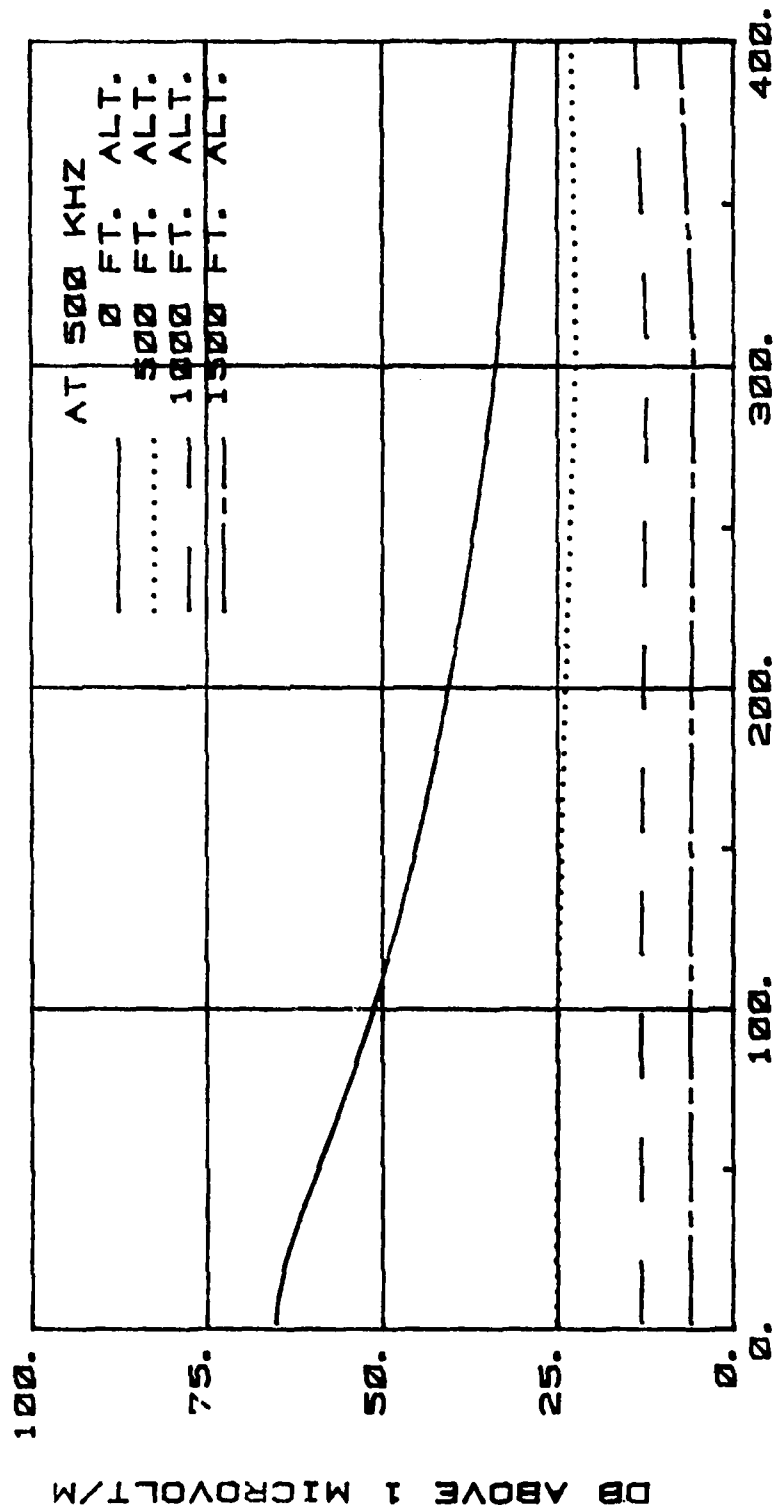
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LATERAL DISTANCE FROM POSITIVE CONDUCTOR IN FEET

Fig. 3.3b Calculated RI noise profile for a bipolar ±600 kV DC powerline at 500 kHz under fair weather condition.

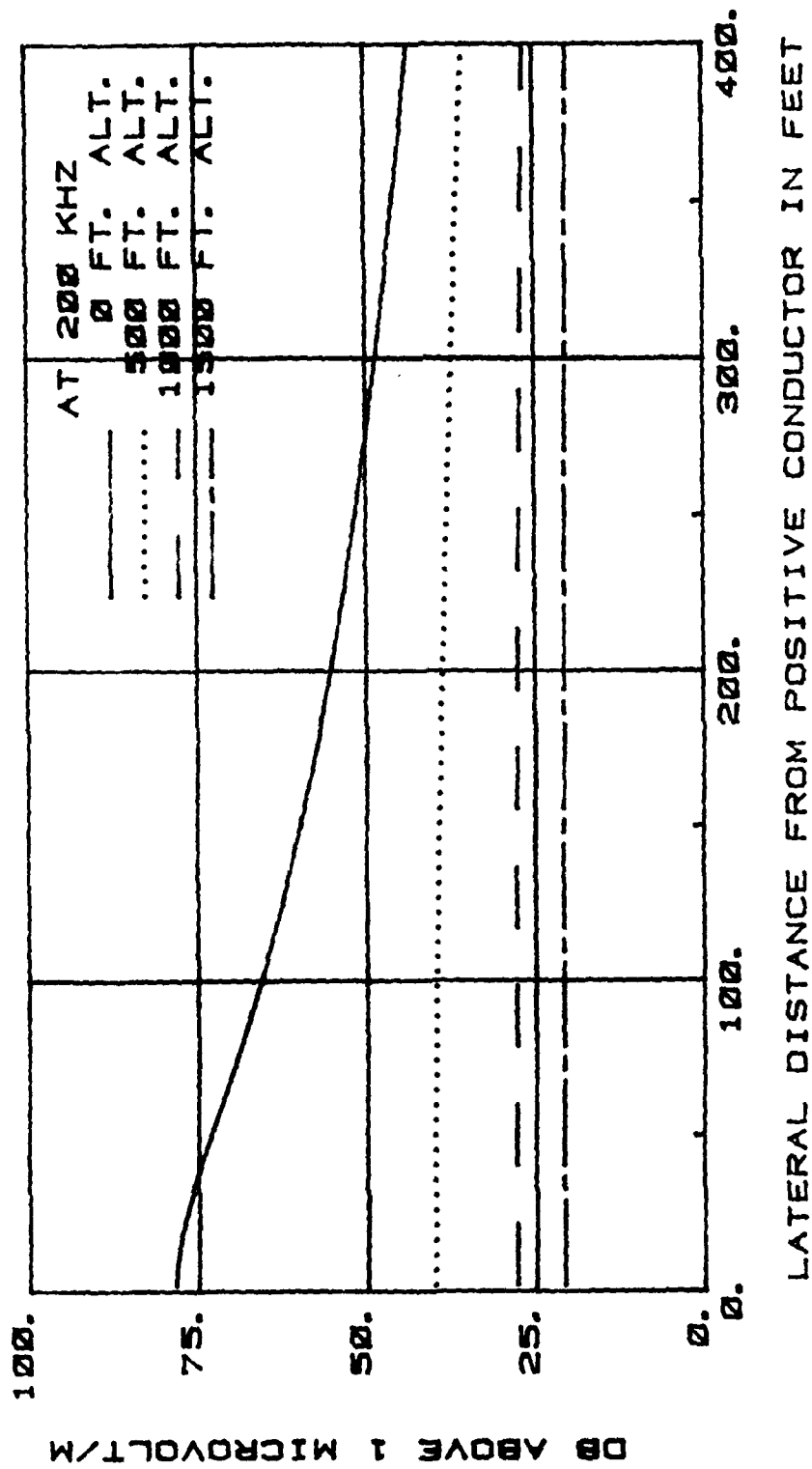


Fig. 3.4a Calculated RI noise profile for a bipolar ± 750 kV DC powerline at 200 kHz under fair weather condition.

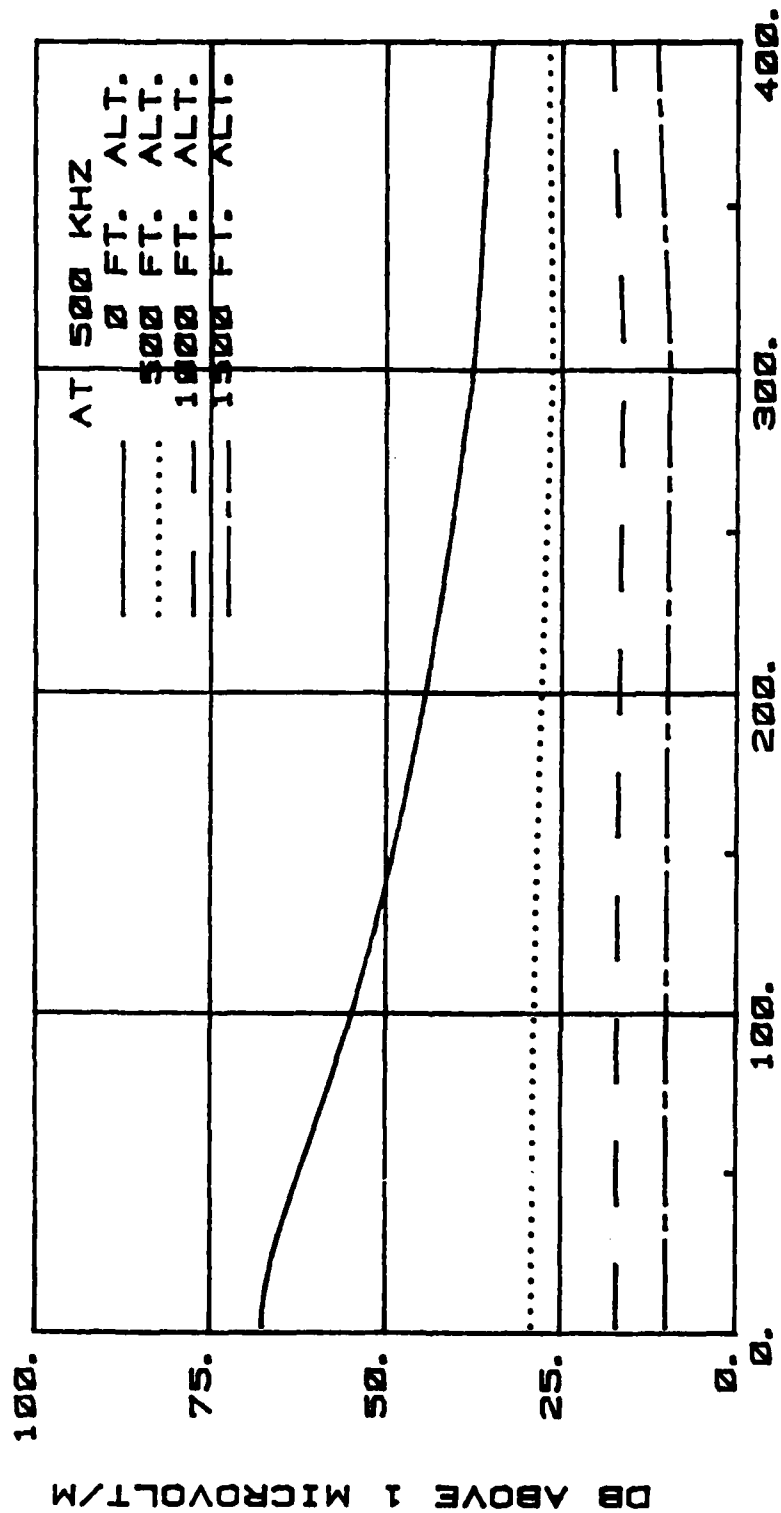


Fig. 3.4b Calculated RI noise profile for a bipolar ± 750 kV DC powerline at 500 kHz under fair weather condition.

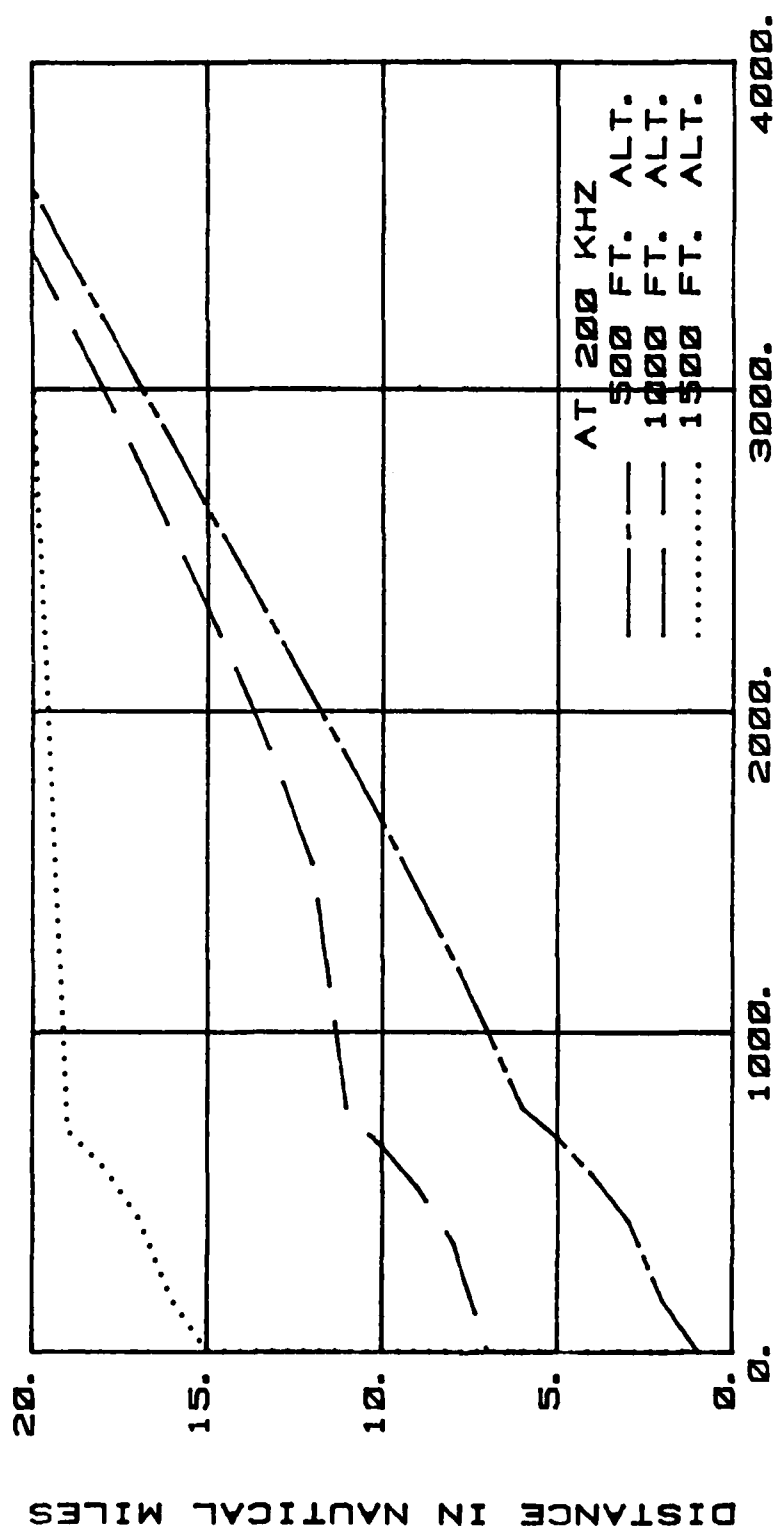


Fig. 3.5a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.05 watt, line voltage = ± 400 kV, $f = 200$ kHz, under fair weather condition.

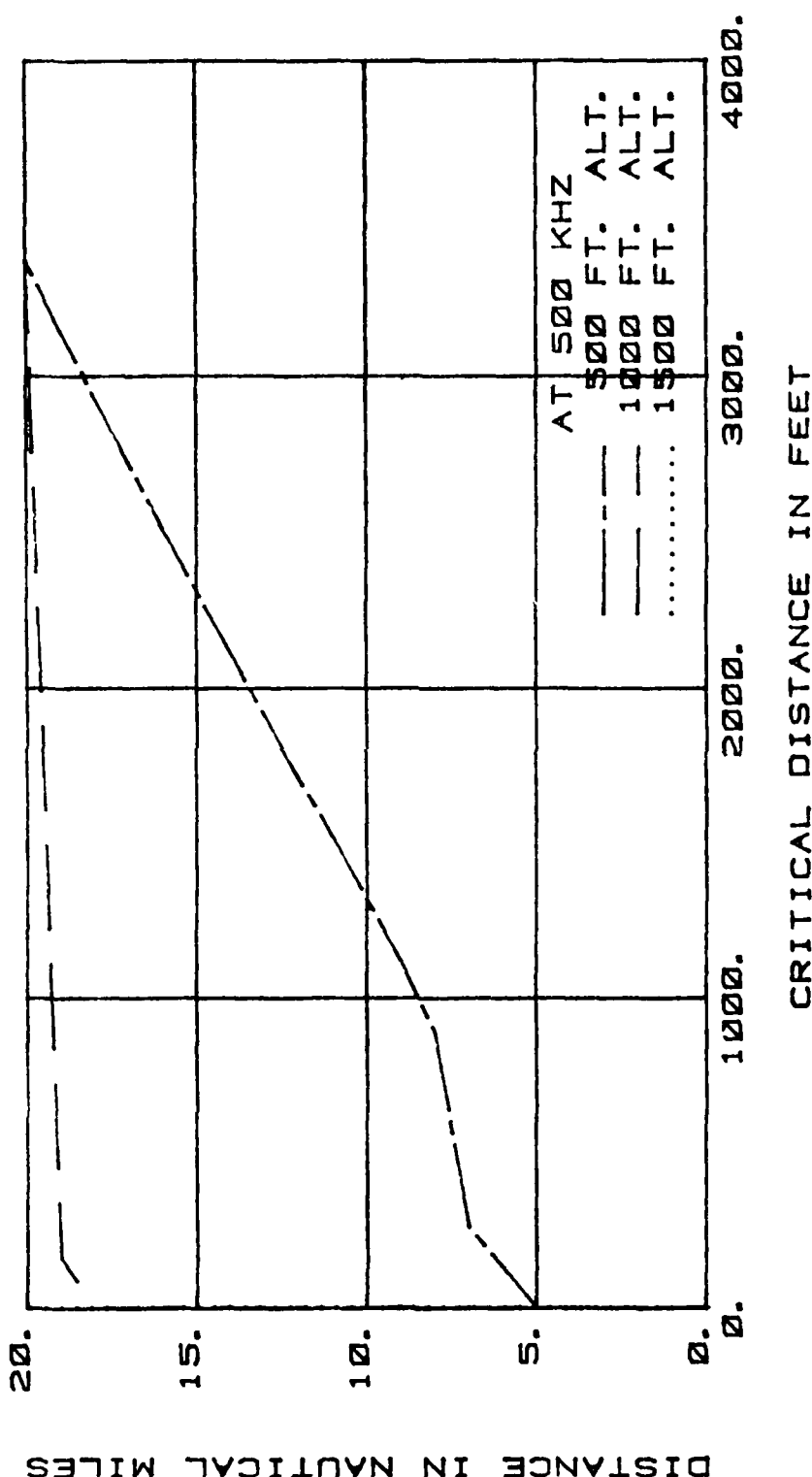
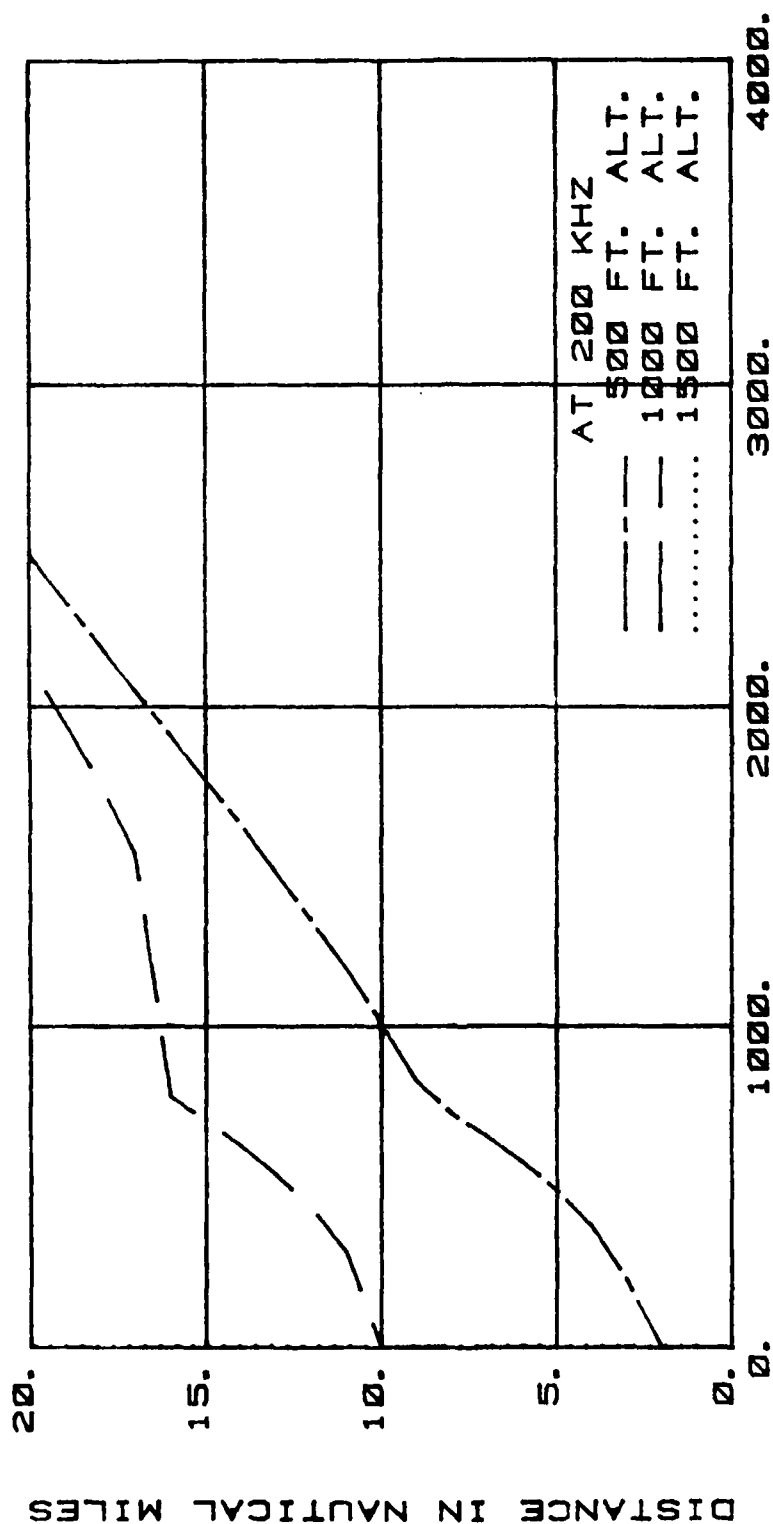


Fig. 3.5b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.05 watt, line voltage = 400 kv, f = 500 kHz, under fair weather condition.



CRITICAL DISTANCE IN FEET

Fig. 3.6a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = ± 400 kV, $f = 200$ KHz, under fair weather condition.

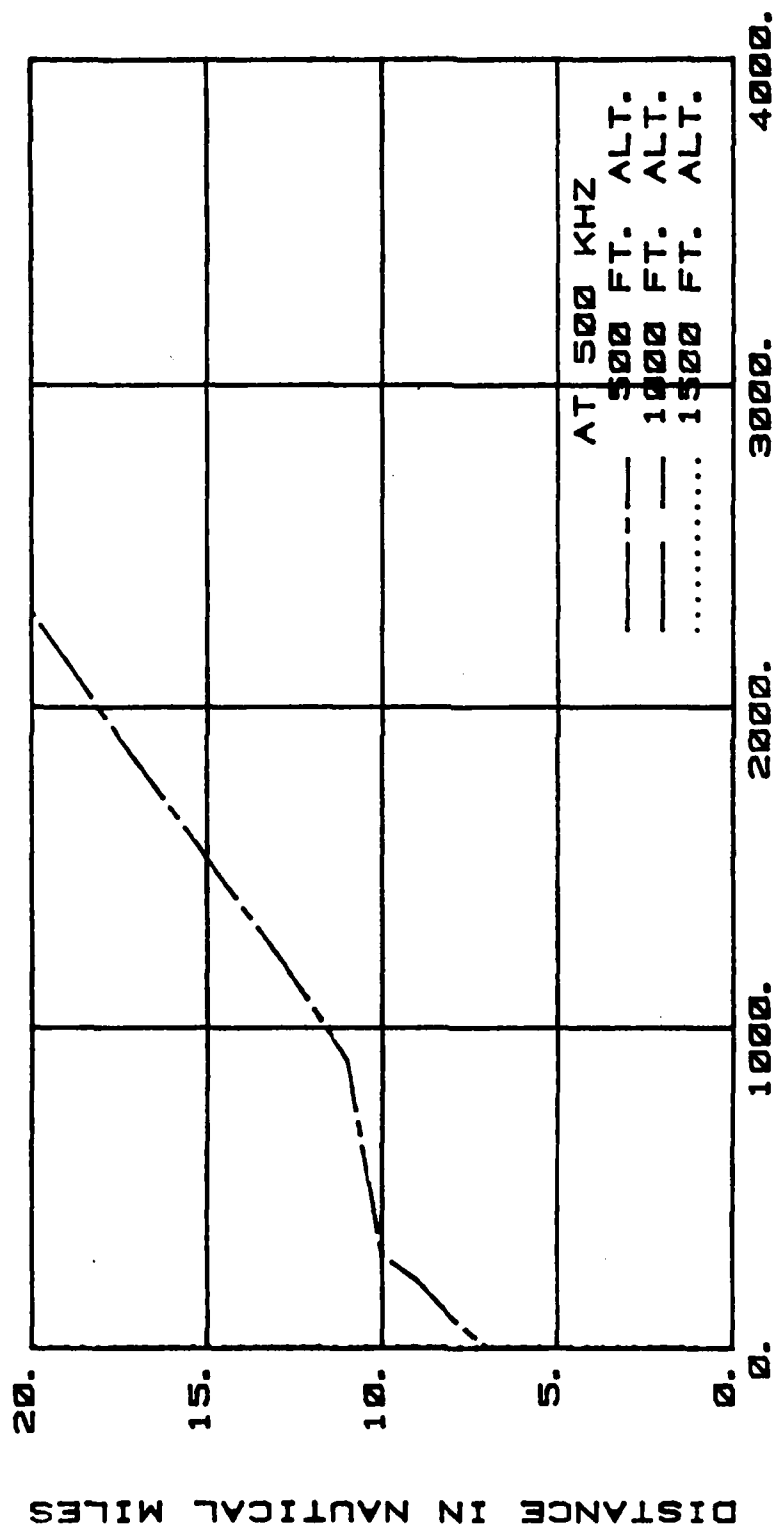


Fig. 3.6b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = ± 400 kv, $f = 500$ kHz, under fair weather condition.

Chapter IV

RERADIATION PREDICTION FROM POWER-LINE STRUCTURES

4.1 Introduction

In order to provide predictions of the possible effects on NDB reception of signals reradiated by large conducting objects, such as power transmission lines, accurately and economically a large scale series of measurements is not feasible. In order to provide a large enough data base for meaningful conclusions a great many airborne measurements of field strength would need to be made. Furthermore, actual sites which would provide suitable situations regarding the relative locations of an NDB and large power line structure would have to be located.

Fortunately, there has been considerable progress made recently in the application of computers to electromagnetic problems. More specifically, techniques have been developed which enable the calculation of induced currents and the resulting reradiated fields on wire structures caused by incident electromagnetic energy provided that the wire structures are small in comparison to the wavelength of the incident field. Since NDB frequencies are so low, even very large mechanical structures, such as sections of power transmission lines, are small in comparison to the NDB wavelengths.

Since these computer techniques have not been previously applied to the situations we are here concerned with, a validation by comparison with measurement seemed appropriate. Measuring the reradiated fields from an actual power line, however, would not be possible due to the

very complex geometry of the structure. Instead, a radio tower has been used for the validation. Since the source of reradiation from a straight vertical tower is localized, the reradiated fields can be measured by using a loop receiving antenna and orienting the loop so as to null the signal coming directly from the NDB. If the geometry is chosen suitably, the loop may simultaneously be oriented so as to, at least approximately, respond maximally to the reradiated fields coming from the tower. A suitable tower is one owned by radio station WRFD in Columbus, Ohio. It is a straight tower 558 feet high. The NDB transmitters in the vicinity are CMH and DKG. The former is operating at 391 Khz with an effective radiated power of 9.683 watts and the latter at 348 Khz with an ERP of 0.6 watt. Fig. 4.1 is a map showing the locations of the tower and the NDB transmitters. The CMH antenna is situated at about 11.72 NM S-23°-E of the tower and that of DKG is at about 5.86 NM S-27°-W. A sketch map is illustrated in Fig. 4.2.

4.2 Measured Results

Measurements were taken along the access road leading to the tower. Equipment used included Interference Analyzer Model EMC-25, Remote Vertical Antenna Model RVR-25 and Remote Loop Antenna Model ALR-25. Measurements were made at five different places along the access road as indicated by Fig. 4.3. In each case the vertical or loop antenna was mounted on a five-foot high tripod.

Results obtained were the total electric field strength as measured by the vertical antenna and the magnetic field strength as measured by the loop antenna. When using the loop antenna two measurements



Fig. 4.1 Map showing the location of the radio tower and the CMH and DKG transmitters in the Columbus area.

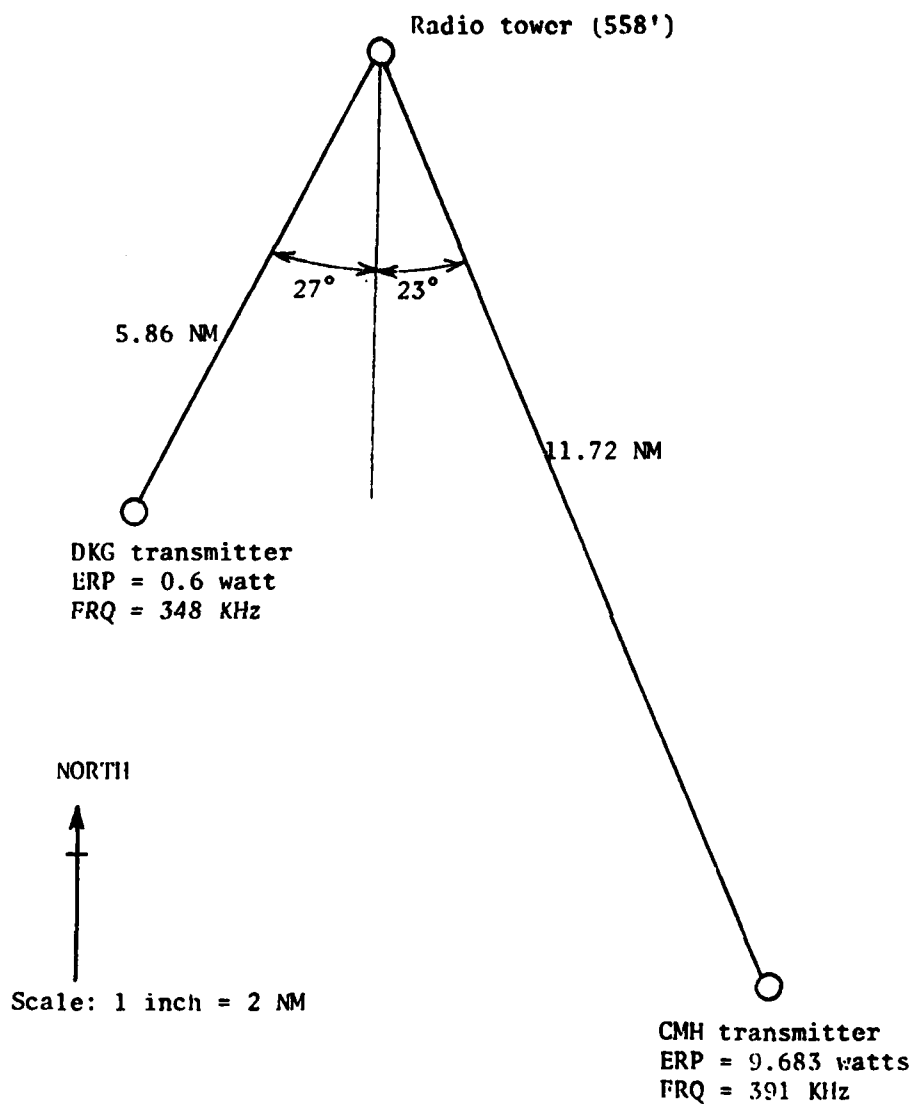


Fig. 4.2 Sketch of the location of radio tower with respect to the CMH and DKG transmitters.

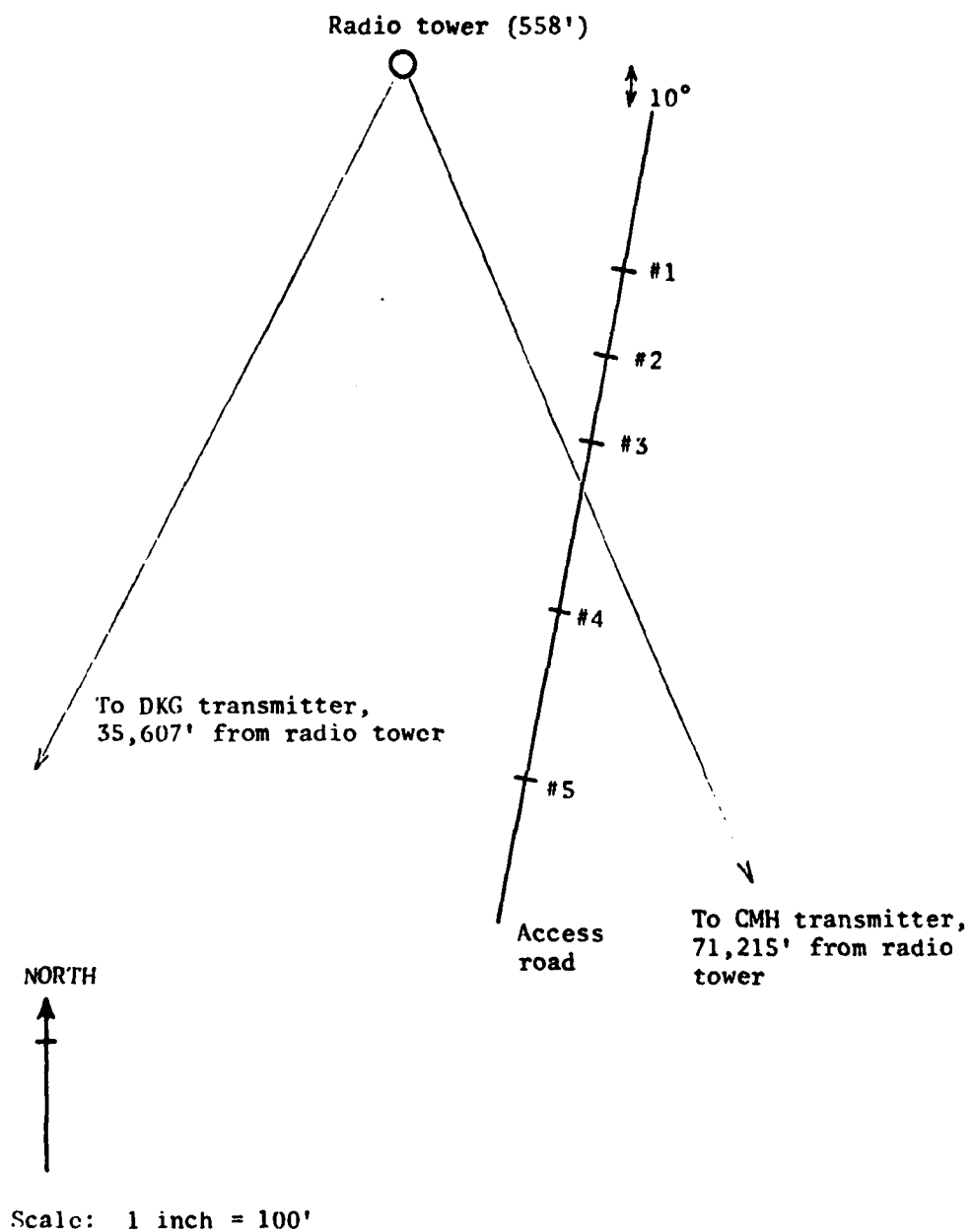


Fig. 4.3 Sketch of the locations of five measuring points with respect to the radio tower and the NDB transmitters.

were made. The loop was rotated in a vertical plane, and the maximum and minimum values of the magnetic field were measured. The maximum value was considered to be primarily due to direct radiation from the NDB, and is denoted the "direct" magnetic field. The total electric and direct magnetic measured fields are listed in Tables 4.3 and 4.4.

4.3 Calculated Results

The calculated results are obtained by using a computer program based on the work of Richmond¹⁵. The program makes use of a mathematical model of the NDB transmitting antenna and the radio tower to compute the electric-field strength for any location. The ground is assumed flat and perfectly conducting, as the major interest is the reradiated signal.

Essentially, the purpose of this preliminary work is to check the accuracy and reliability of using this particular computer program to predict signal reradiation. The test involves comparison of the measured results and the calculated results that are obtained by using the mathematical models that simulate the same physical situation.

The coordinates of the five measuring locations with respect to each transmitting antenna are shown in Tables 4.1 and 4.2. In each case the x-axis is the imaginary line that passes through the NDB antenna and the reflecting tower with the former being the origin. The electric field strength of the direct signal from the NDB transmitters, the reradiated signal from the tower and the total electric-field strength are calculated along the access road with respect to CMH and DKG. These are illustrated in Fig. 4.4 and 4.5. In addition, Fig. 4.6 shows the calculated behavior of the total electric-field

Location	x-coordinate (feet)	y-coordinate (feet)	z-coordinate (feet)
# 1	71,065.0	-71.7	5.00
# 2	71,020.0	-42.3	5.00
# 3	70,980.0	-16.1	5.00
# 4	70,895.0	39.6	5.00
# 5	70,815.0	92.0	5.00

Table 4.1. Coordinates with respect to CMH transmitter.
The x-axis originates at the NDB and passes
through the reflecting radio tower.

Location	x-coordinate (feet)	y-coordinate (feet)	z-coordinate (feet)
# 1	35,557.0	-168.0	5.00
# 2	35,509.5	-185.6	5.00
# 3	35,462.0	-203.2	5.00
# 4	35,367.0	-238.3	5.00
# 5	35,269.5	-274.4	5.00

Table 4.2. Coordinates with respect to DKG transmitter.
The x-axis originates at the NDB and passes through
the reflecting radio tower.

along the x-axis for ± 300 feet from the tower for the CMH transmitter. Fig. 4.7 illustrates the similar characteristics for the DKG transmitting antenna. In both cases the curves are smooth as expected and the total electric-field strength levels increase at points closer to the tower due to the fact that the reradiated signal strength is higher in this region. The peak value of the tower electric-field strength that coincides with the location of the tower should be ignored as this value is not valid. The computer model cannot handle points inside a conductor.

4.4 Comparison of the Measured and Calculated Results for Direct and Total Fields

Measured results obtained by using the vertical antenna are compared with the calculated total electric-field strength. Fig. 4.4a and 4.5a show the levels of the total electric-field strength for the CMH and DKH transmitting antenna respectively, and comparison between the measured and calculated results can be made directly. For convenience, Tables 4.3 and 4.4 provide the comparison for the five measuring locations.

In the calculated results, the electric-field strength of the direct signal from the transmitting antenna could be converted to a magnetic-field strength by using the equation $\eta = E/H$, when η is the intrinsic impedance of the medium and could be assumed to be approximately 120 . The measured levels of the magnetic-field strength (with loop oriented for maximum signal) for the CMH and DKG transmitters are also shown in Fig. 4.4b and 4.5b respectively. Comparisons are given as well in Tables 4.5 and 4.6.

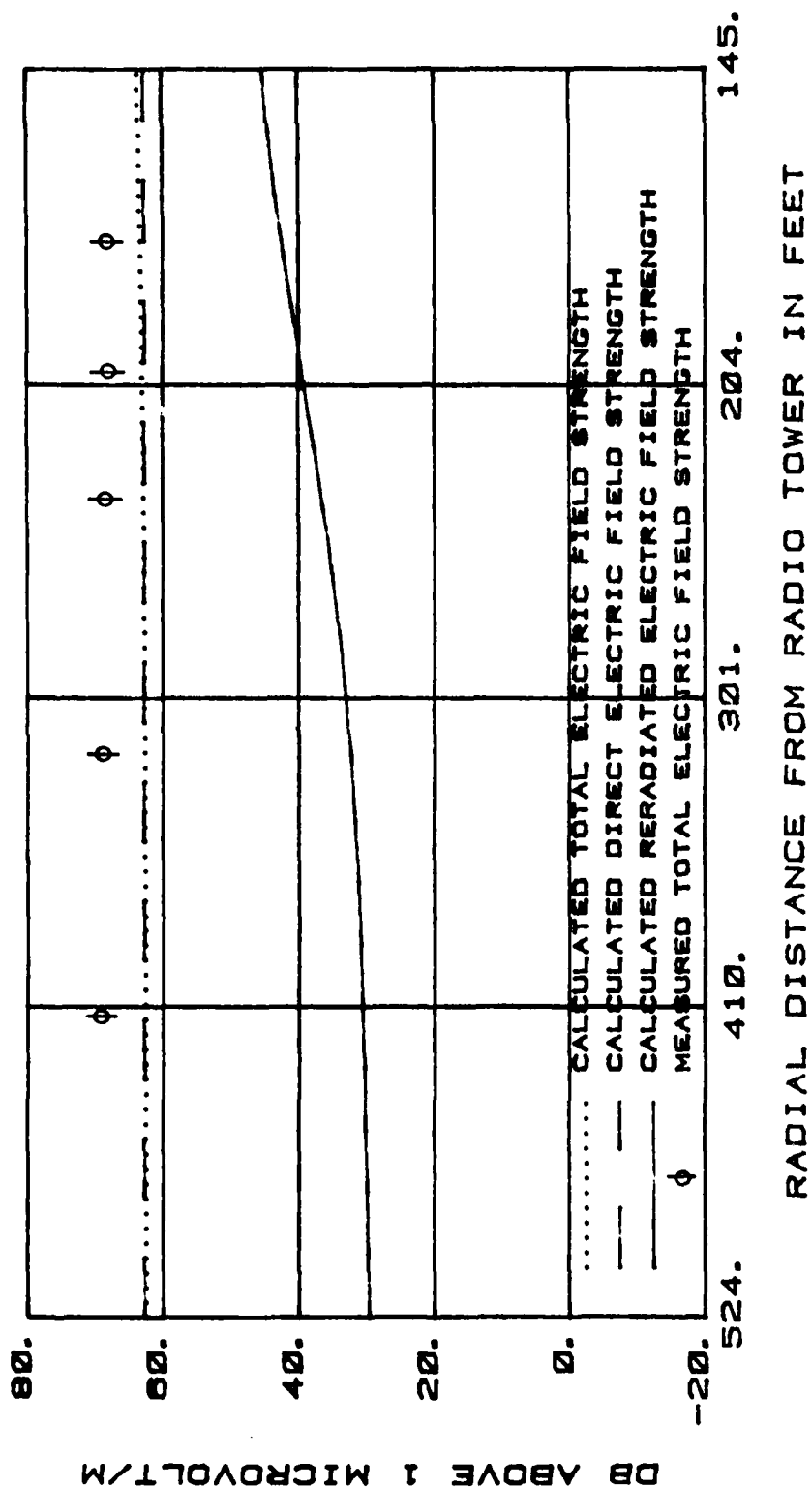


Fig. 4.4a Calculated and measured values of electric field strength along the access road with respect to CMH transmitter.

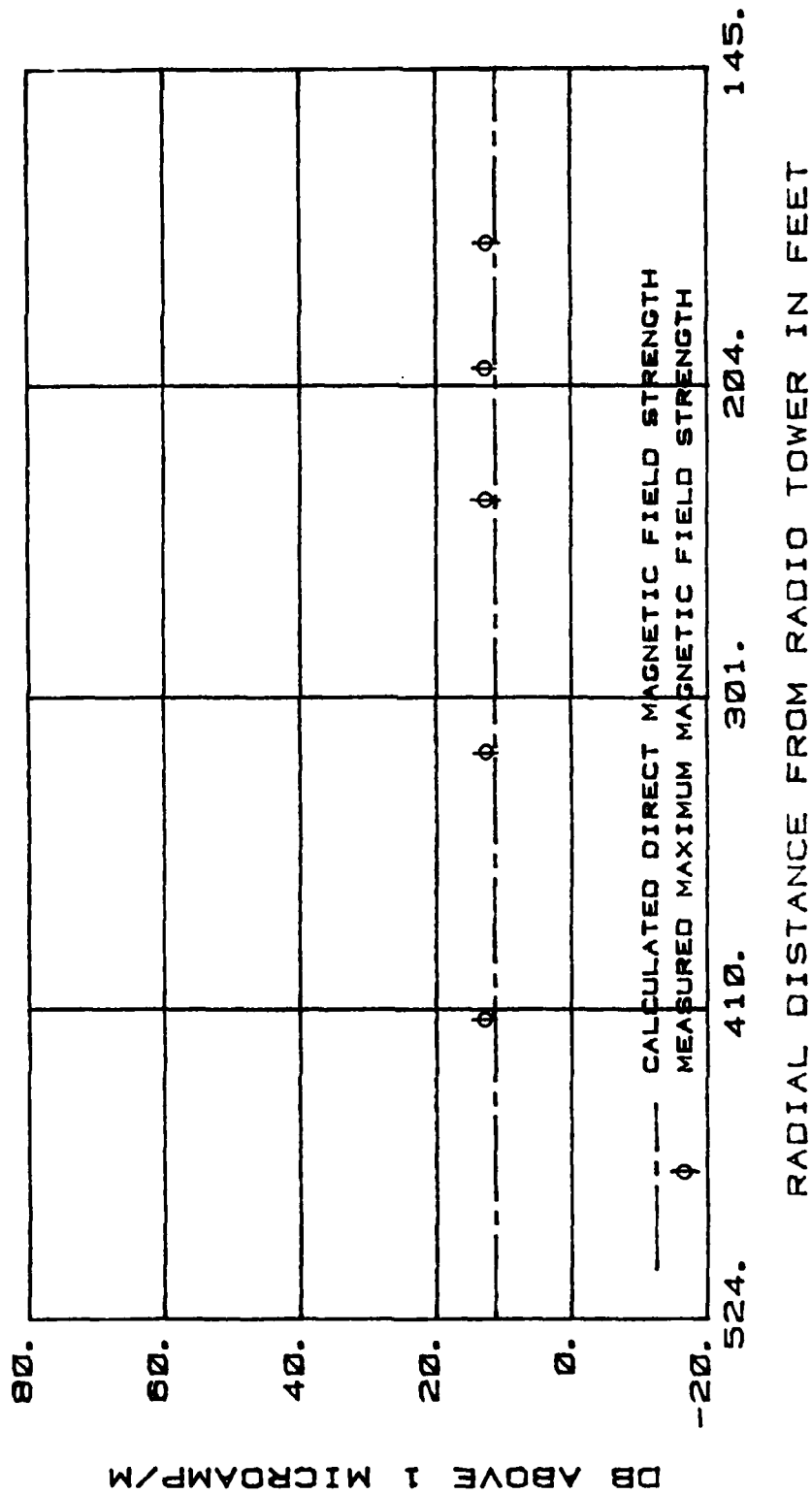


Fig. 4.4b Calculated values of radiated magnetic field strength and measured maximum magnetic field strength along the access road with respect with CMH transmitter.

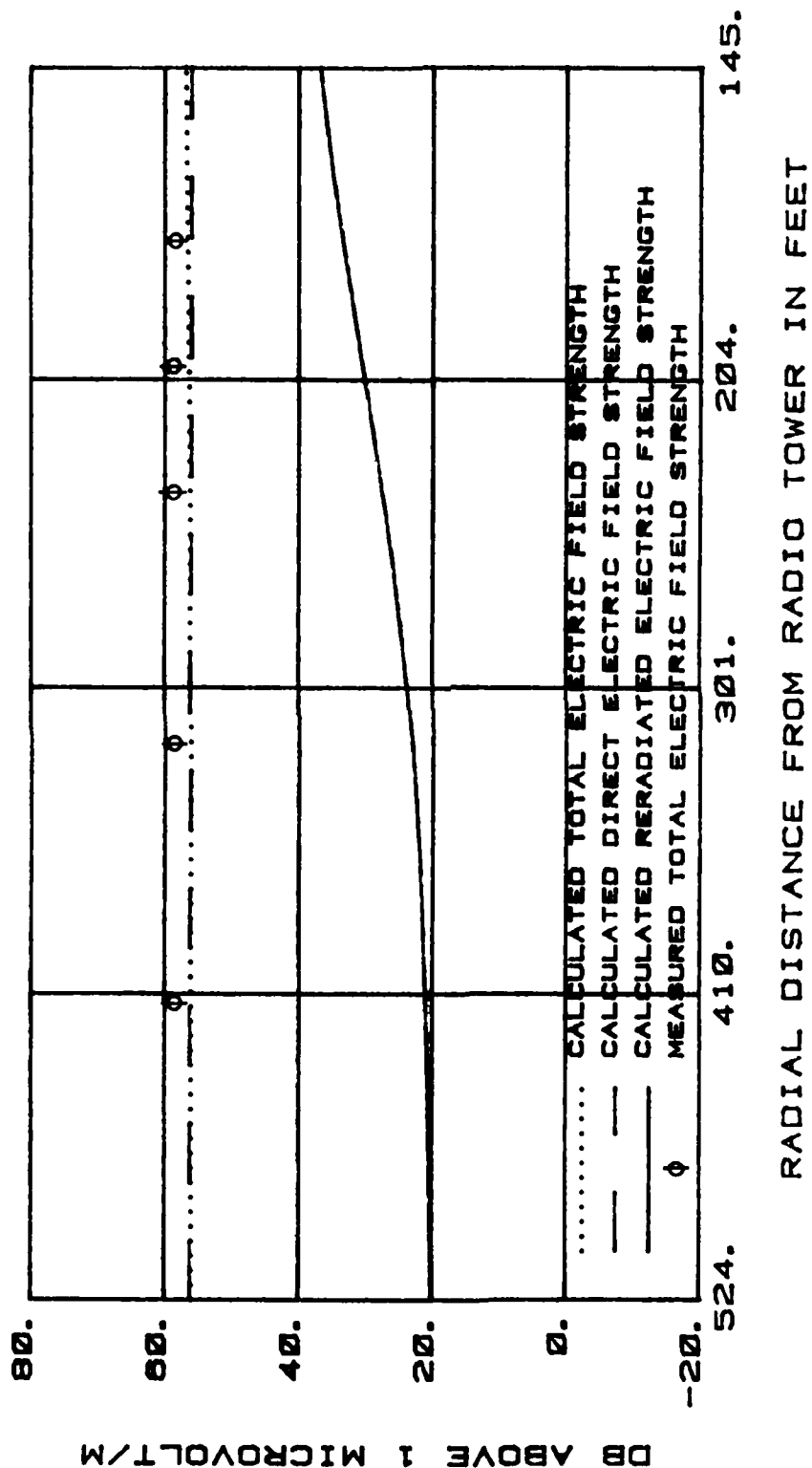


Fig. 4.5a Calculated and measured values of electric field strength along the access road with respect to DKG transmitter.

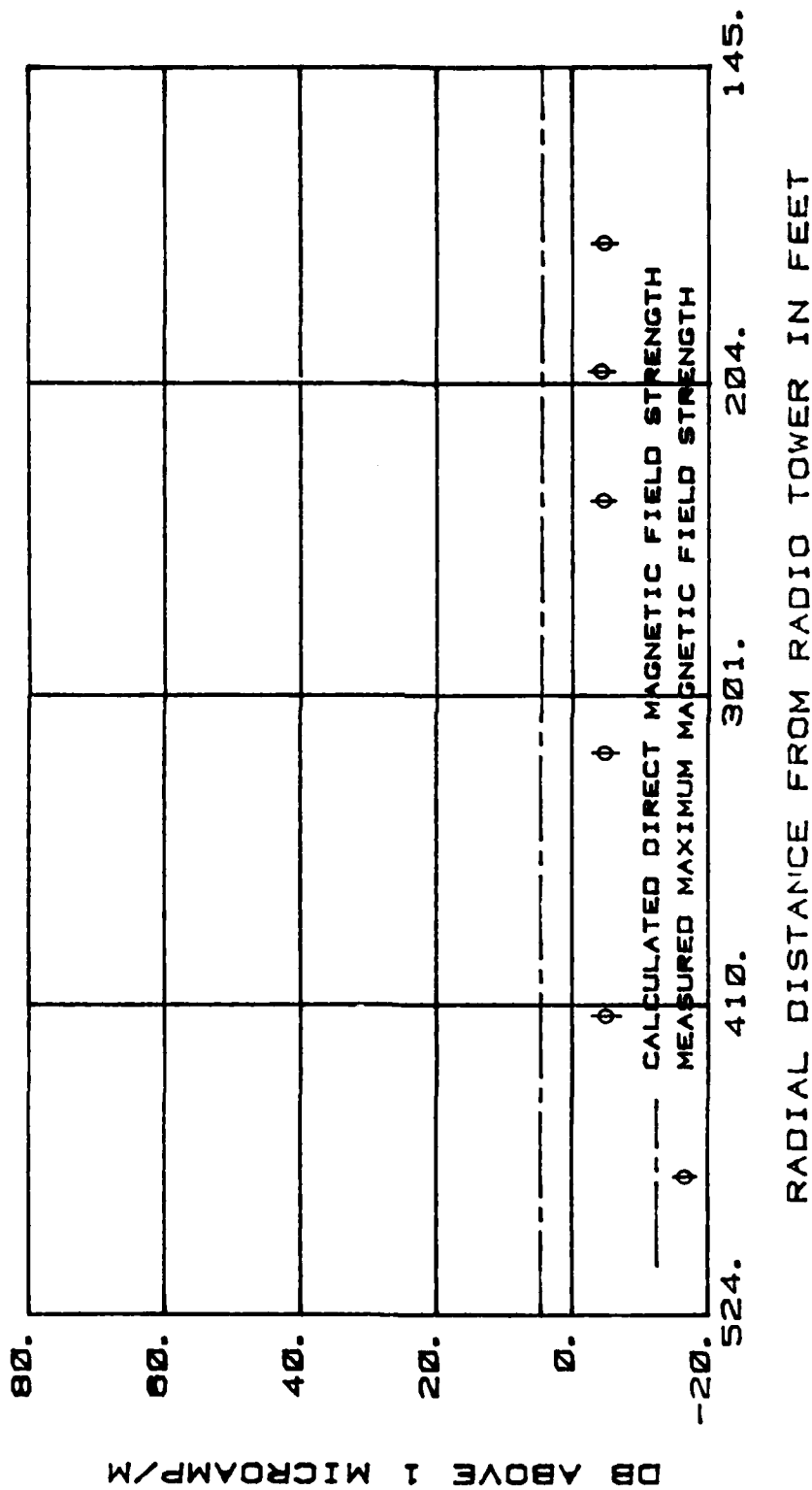


Fig. 4.5b Calculated values of radiated magnetic field strength and measured maximum magnetic field strength along the access road with respect to DKG transmitter.

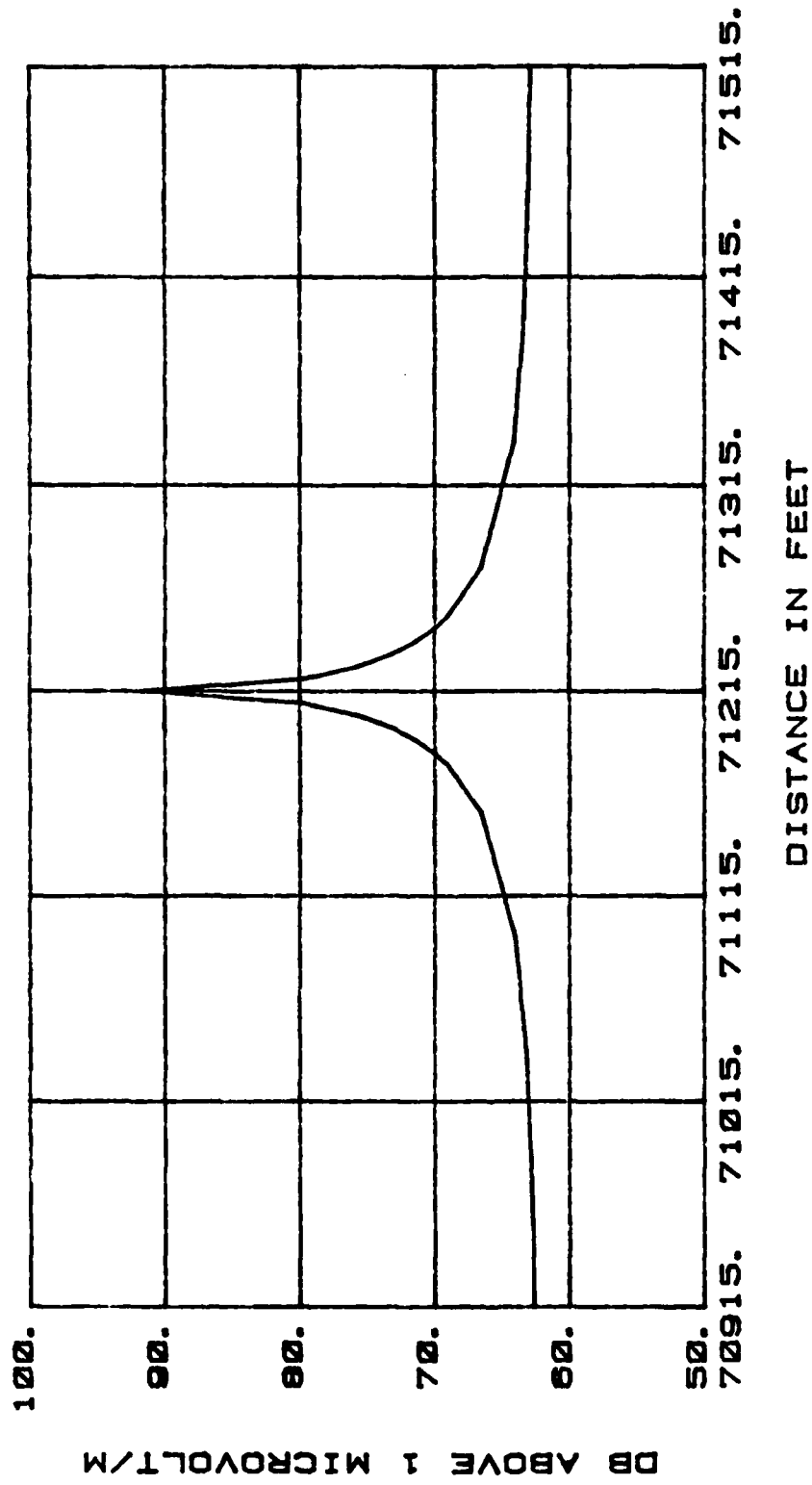


Fig. 4.6 Calculated values of the total electric field strength with respect to CMH transmitter along the x-axis, originating at the NDB antenna and passing through the tower.

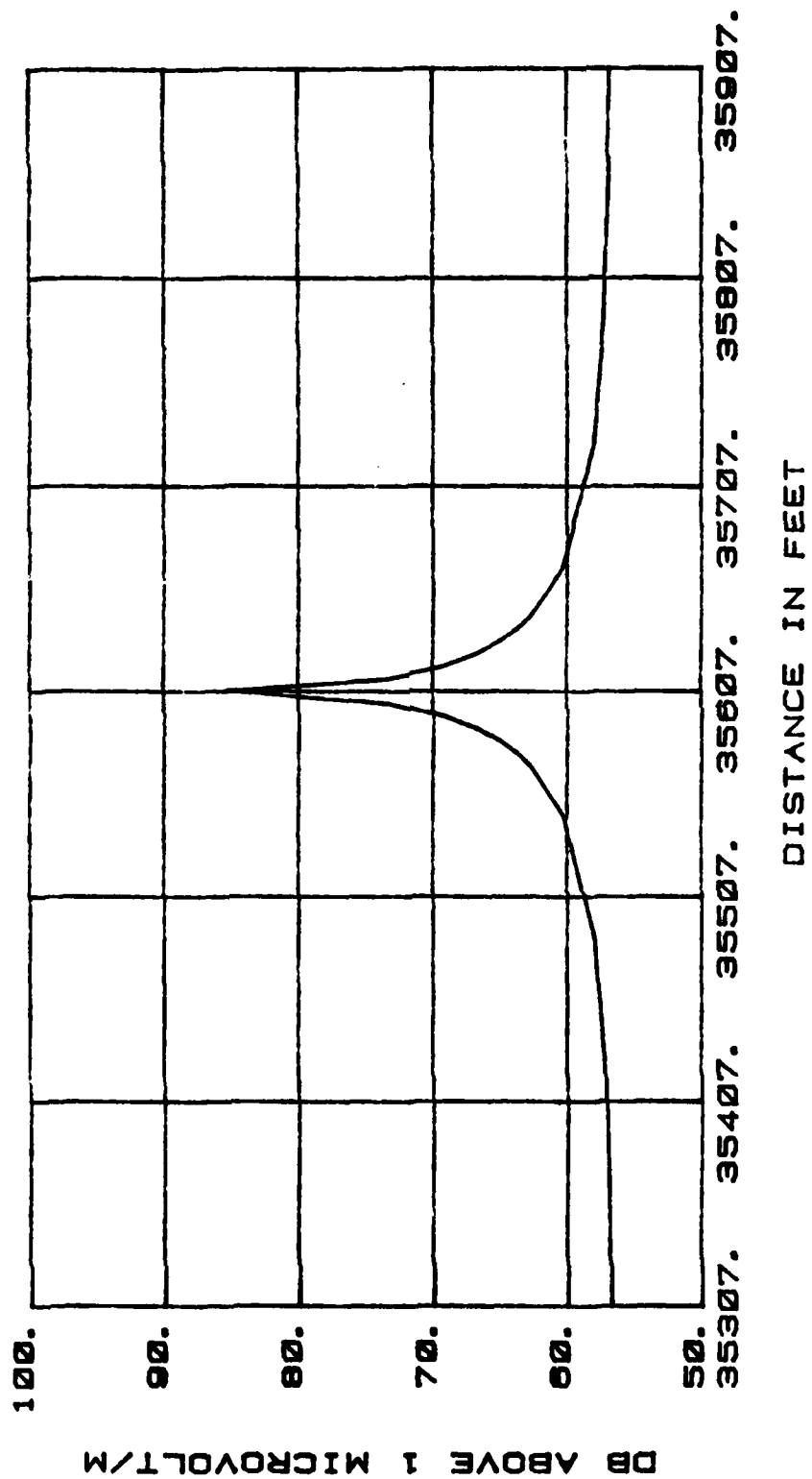


Fig. 4.7 Calculated values of the total electric field strength with respect to DKG transmitter along the x-axis, originating at the NDB antenna and passing through the tower.

Location	Measured Results (dB/ μ V/m)	Calculated Results (dB/ μ V/m)	Difference (dB/ μ V/m)
# 1	69.6	63.3	6.3
# 2	68.6	63.0	5.6
# 3	68.6	62.8	5.8
# 4	68.6	62.6	6.0
# 5	68.6	62.5	6.1

Table 4.3. Total electric-field strength comparison for CMI transmitter. Measurements made using vertical monopole antenna

Location	Measured Results (dB/ μ V/m)	Calculated Results (dB/ μ V/m)	Difference (dB/ μ V/m)
# 1	59.8	57.30	2.50
# 2	59.8	57.05	2.75
# 3	59.8	56.90	2.90
# 4	59.3	56.70	2.60
# 5	58.8	56.65	2.15

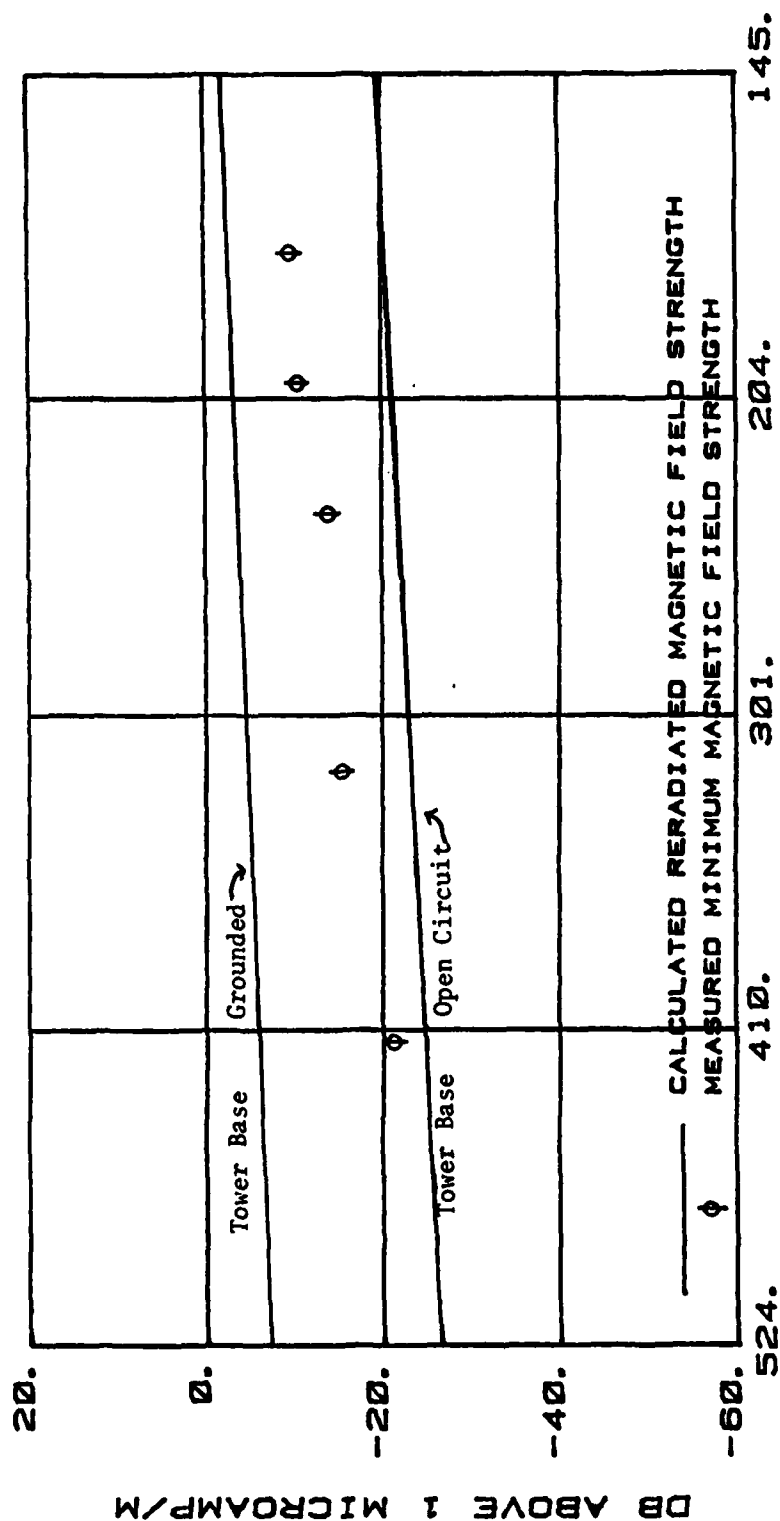
Table 4.4. Total electric-field strength comparison for DKG transmitter. Measurements made using vertical monopole antenna.

Location	Measured Results (dB/ μ A/m)	Calculated Results (dB/ μ A/m)	Difference (dB/ μ A/m)
# 1	11.9	11.165	0.735
# 2	11.4	11.170	0.230
# 3	11.9	11.175	0.725
# 4	11.9	11.186	0.714
# 5	11.9	11.196	0.704

Table 4.5. Direct magnetic-field strength comparison for CMH transmitter. Measured results are for loop oriented for maximum response.

Location	Measured Results (dB/ μ A/m)	Calculated Results (dB/ μ A/m)	Difference (dB/ μ A/m)
# 1	-2.4	5.20	-7.60
# 2	-1.9	5.20	-7.10
# 3	-1.4	5.22	-6.62
# 4	-1.4	5.24	-6.64
# 5	-2.4	5.25	-7.65

Table 4.6. Direct magnetic-field strength comparison for DKG transmitter. Measured results are for loop oriented for maximum response.



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Fig. 4.8 Calculated values of reradiated magnetic field strength and measured minimum magnetic field strength (nulled direct radiation) along the access road with respect to DKG transmitter.

4.5 Near-Zone Magnetic-Field Strength Comparison of Calculated and Measured Reradiated Fields

When the loop antenna used to measure magnetic field strength at the access road measurement points was rotated to the minimum signal position for the DKG signal, the direct signal from the NDB was approximately in the loop null. At all the five measuring locations, the alignment of the loop was simultaneously such that strong coupling existed with the currents induced on the tower.

The values of the magnetic field measured then were due primarily to the reradiated signal from the tower, other interfering signals, and noise. Unfortunately, this situation did not happen for the CMII transmitting antenna. Thus only DKG signals are compared in this section.

For near-zone reradiated magnetic-field strength calculation, a further separate computation, also based on the work of Richmond^[16] was necessary. The calculated results are shown in Fig. 4.8 and comparison with the measured values is listed in Table 4.7.

Location	Measured Results (dB/ μ A/m)	Calculated Results (dB/ μ A/m)	Difference (dB/ μ A/m)
# 1	-9.4	-19.4	10.0
# 2	-11.4	-20.3	8.9
# 3	-13.4	-21.2	7.8
# 4	-16.4	-23.1	6.7
# 5	-20.4	-24.8	4.8

Table 4.7 Near-zone reradiated magnetic-field comparison for the DKG transmitter. Measured results are for the loop oriented for minimum response.

The base of the tower is insulated from ground, and therefore the calculated values in Table 4.7 were made for this condition. The measured results are consistently higher than these calculated results indicating that more current was induced in the actual tower than predicted by the computer model. The actual tower is fed at the base through a matching device which provides a current path from the tower base to ground. However, this impedance could not be conveniently measured since the radio station broadcast 24 hours per day, nor did the station engineer have this information. However, the calculations were repeated with the tower base shorted to ground, and both open and short circuit results are shown in Fig. 4.8. The measured results for the actual tower lie nearly midway between the two calculated curves. Since the problem is linear, one would expect that if the correct tower-to-ground impedance were input to the model, the discrepancy would necessarily be less than indicated in Fig. 4.8, which is on the order of 10 dB. Also, since transmission line towers are well-grounded, this ambiguity will not exist in the intended application, and the conclusion is that the computer modeling program is valid for predicting reradiated signal levels at NDB frequencies.

4.6 Prediction of the reradiated/direct signal ratio for various powerline tower models.

At this point, we are able to investigate the levels of reradiated signals from various powerline tower models by using the computer modeling program. For this purpose, three different tower configurations are being considered. Their detailed dimensions are shown in Fig. 4.9. Each tower, in turn, is placed at 1 NM mile away from the NDB transmitter along the imaginary x-axis, which is passing through the transmitter and the powerline tower with the former being the

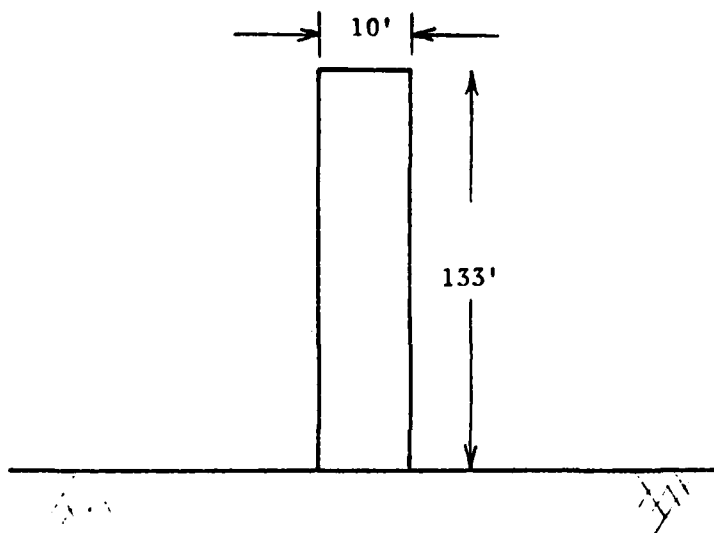


Fig. 4.9a Model of double wire steel tower

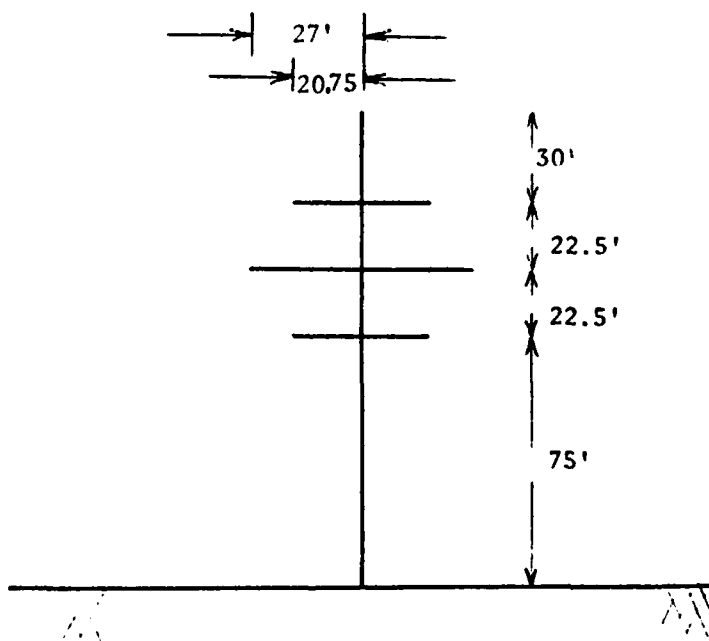


Fig. 4.9b Model of single steel tower with cross arms

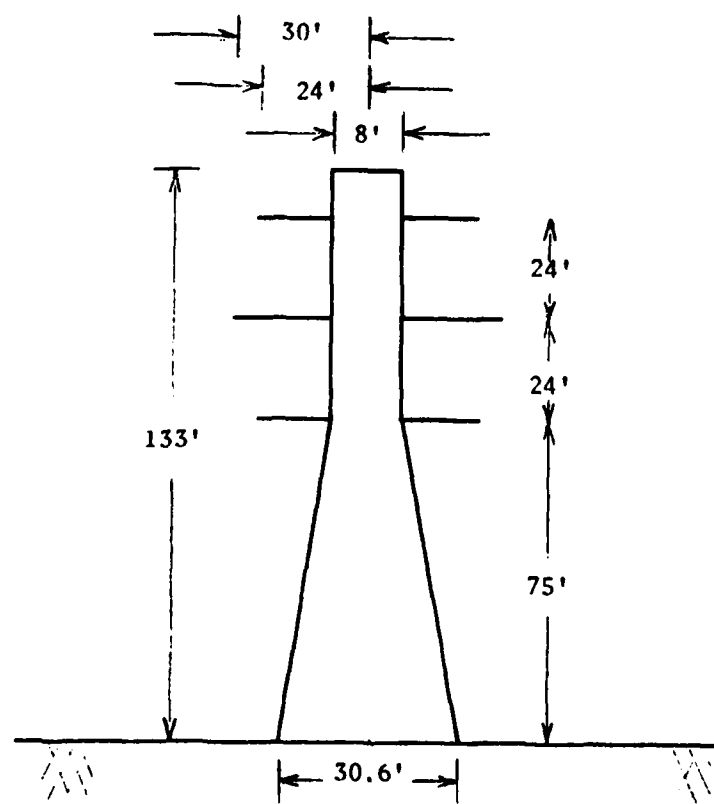


Fig. 4.9c Model of double steel tower with cross arms

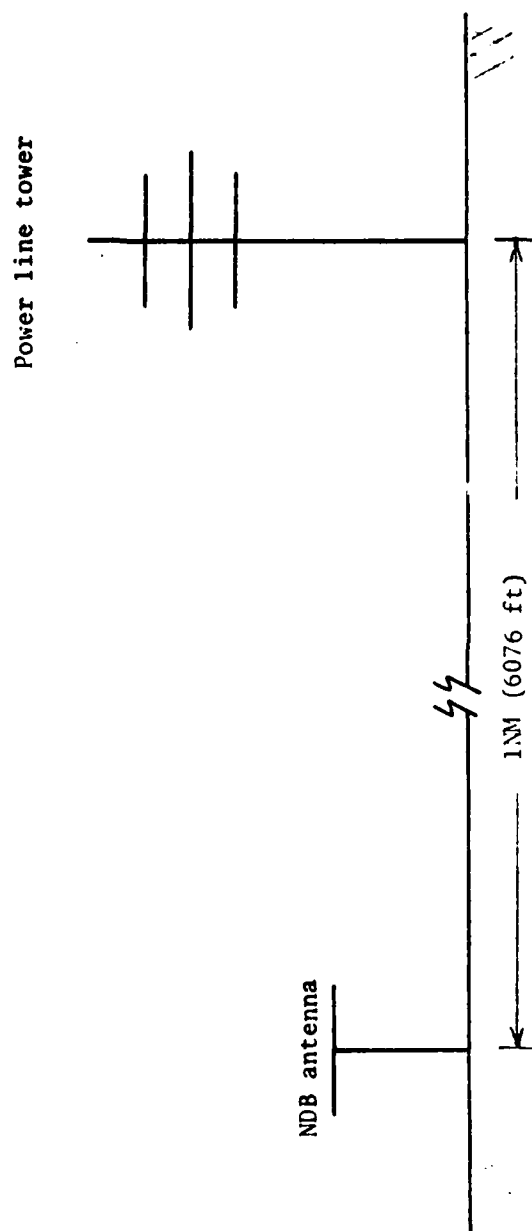


Fig. 4.10 A general layout of a powerline tower model with respect to an NDB transmitter.

origin, as illustrated in Fig. 4.10.

The reradiated/direct signal ratio is computed along the x-axis within ± 200 feet from the tower and the receiver altitudes are at 500, 1000 and 1500 feet above ground respectively. The value of ERP of the NDB transmitter is immaterial for this purpose as only the ratio of the reradiated/direct signal is being investigated. Any value of ERP of the NDB transmitter will be cancelled out in the computation for the reradiated/direct signal ratio. Similarly, the distance separating the NDB transmitter and the powerline tower does not affect the ratio greatly either. In fact, as the separating distance increases, the reradiated/direct signal ratio decreases.

The levels of the reradiated/direct signal ratio for the three different tower models at the frequencies of 200 and 500 KHz are shown in Fig. 4.11. The plots consistently show that the reradiated/direct signal ratio is much lower than the critical value of -15 dB. It appears that the different powerline tower models do not affect the reradiated/direct signal ratio a great deal, as indicated by Fig. 4.11. Based on this observation, a simplified powerline tower model, as shown in Fig. 4.12, can be conveniently used for further investigation. Fig. 4.13 confirms that the reradiated/direct signal ratio of this simplified powerline tower model is comparable to those of the three different tower models.

Using this simple tower model, a general layout as shown in Fig. 4.14, can be considered. Three tower models are placed 1000 feet apart and their alignment is perpendicular to the x-axis at 1 NM away from the NDB transmitter. The resulting reradiated/direct signal ratio is shown in Fig. 4.15. The plots indicate that the reradiated/direct

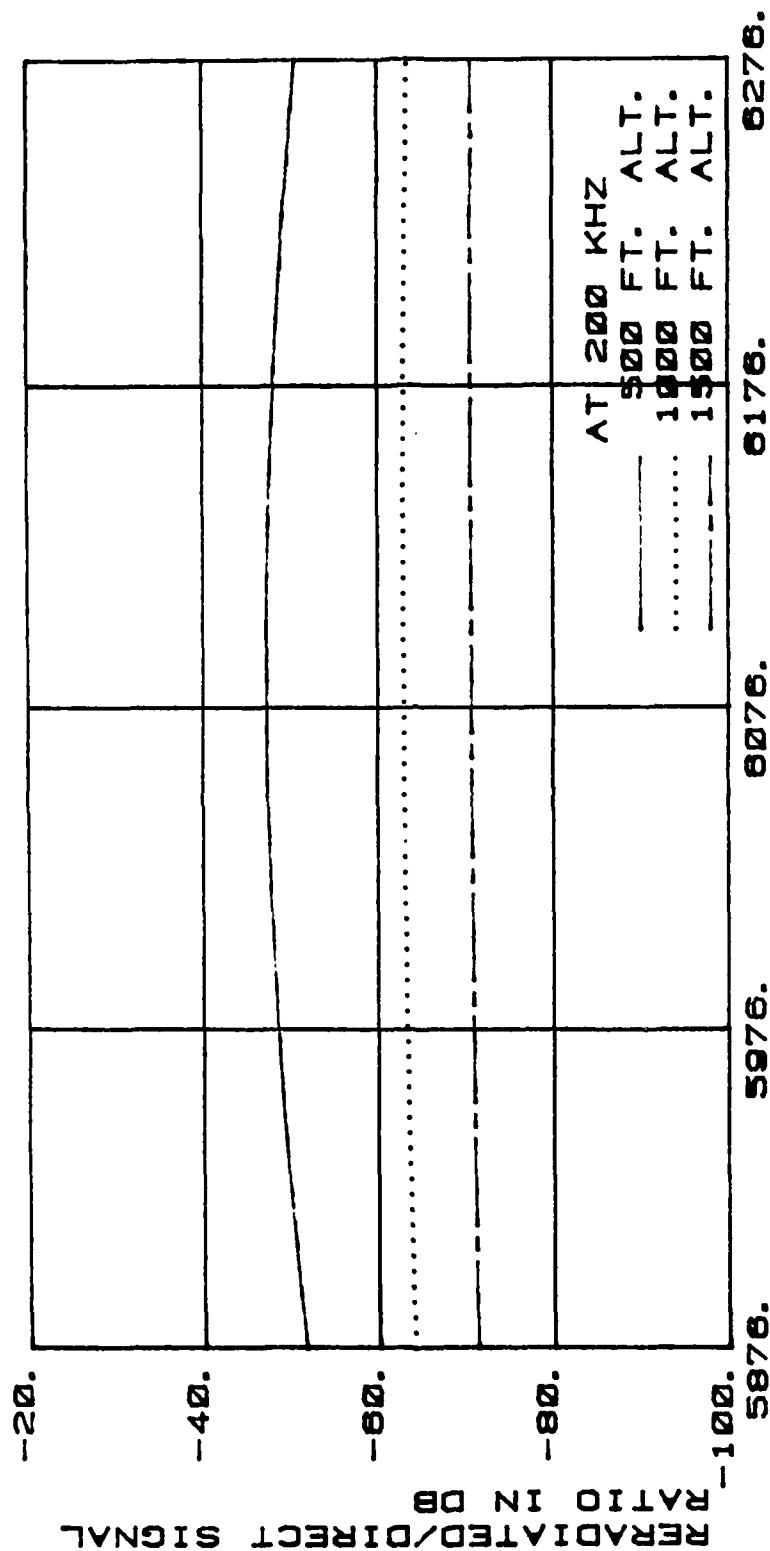
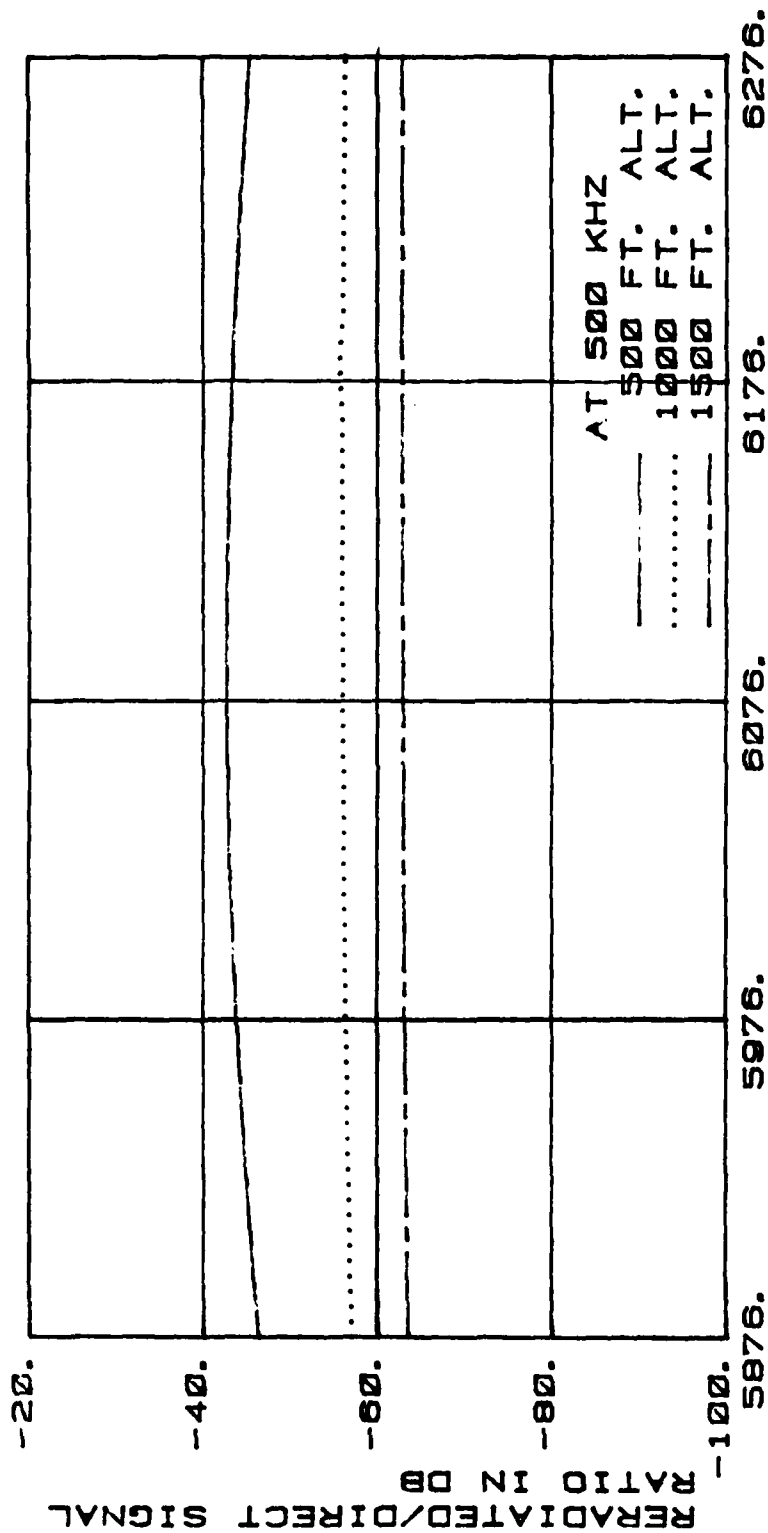


Fig. 4.11a Reradiated/direct signal ratio for double wire steel tower model at 200 KHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the tower.



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Fig. 4.11b Reradiated/direct signal ratio for double wire steel tower model at 500 KHz vs distance from the NDB. The tower is at 6076 feet (1 MI) and the flight path is directly over the tower.

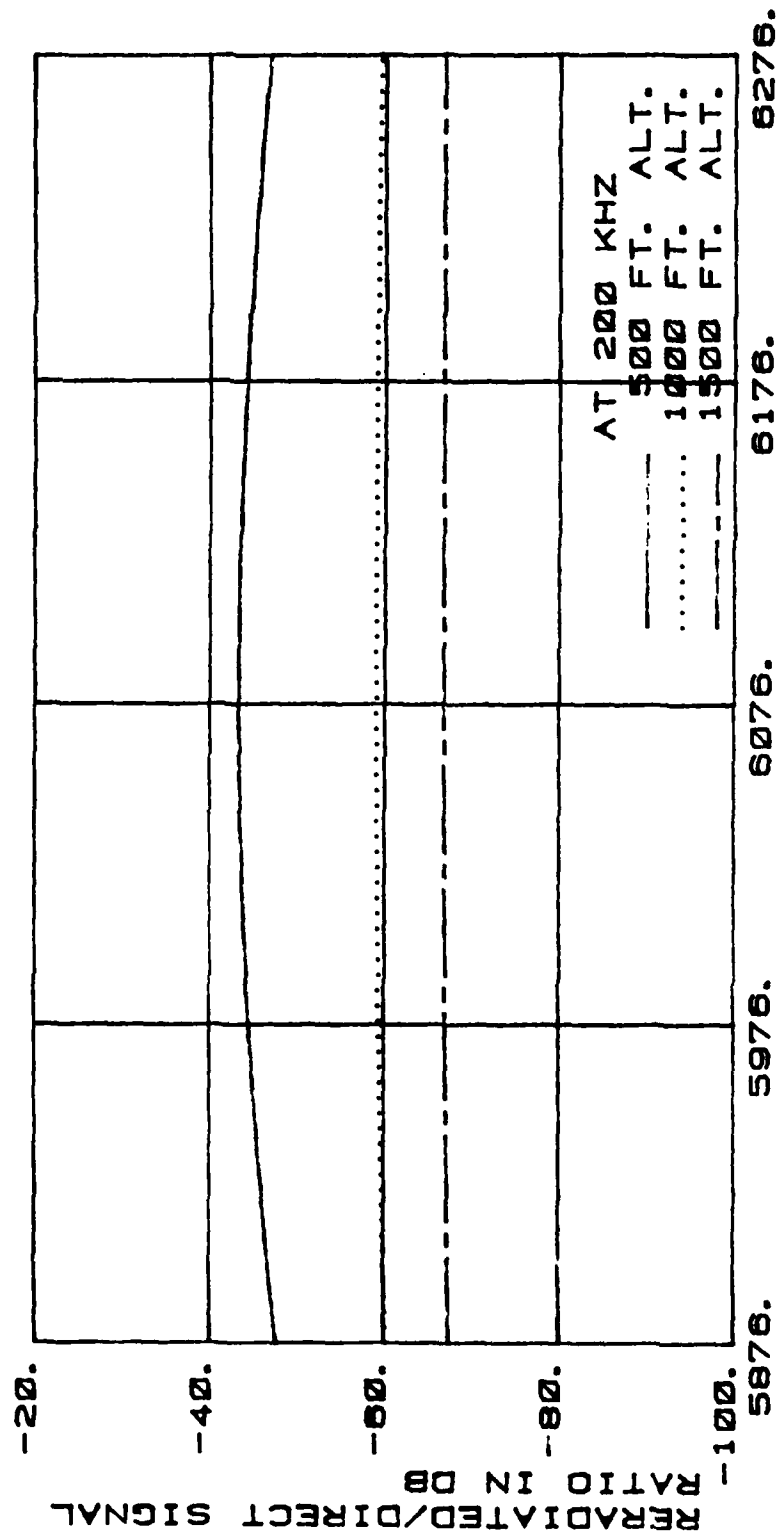


Fig. 4.11c Reradiated/direct signal ratio for single steel tower model with cross arms at 200 KHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the tower.

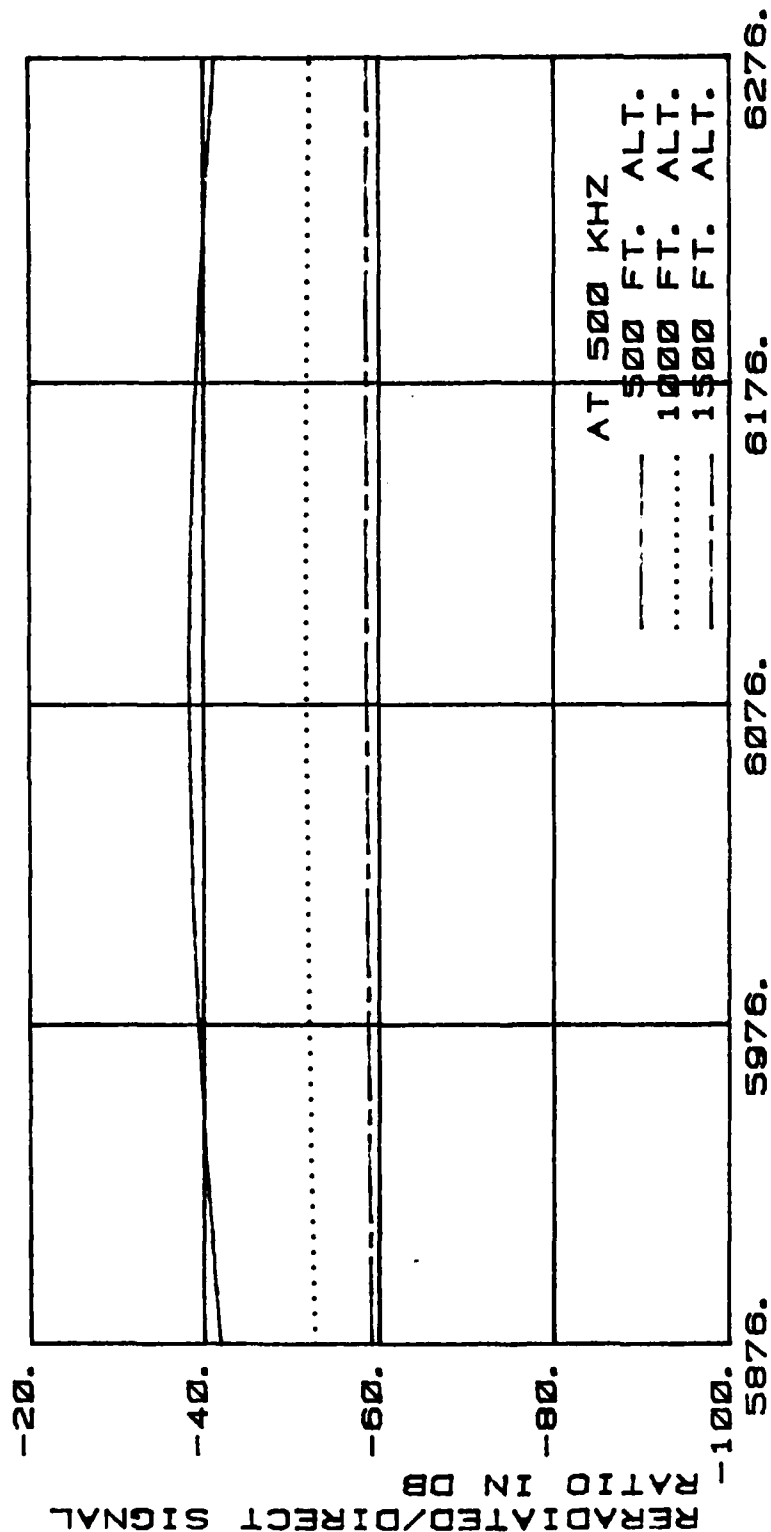


Fig. 4.1ld Reradiated/direct signal ratio profile for the single steel tower model with cross arms at 500 KHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the tower.

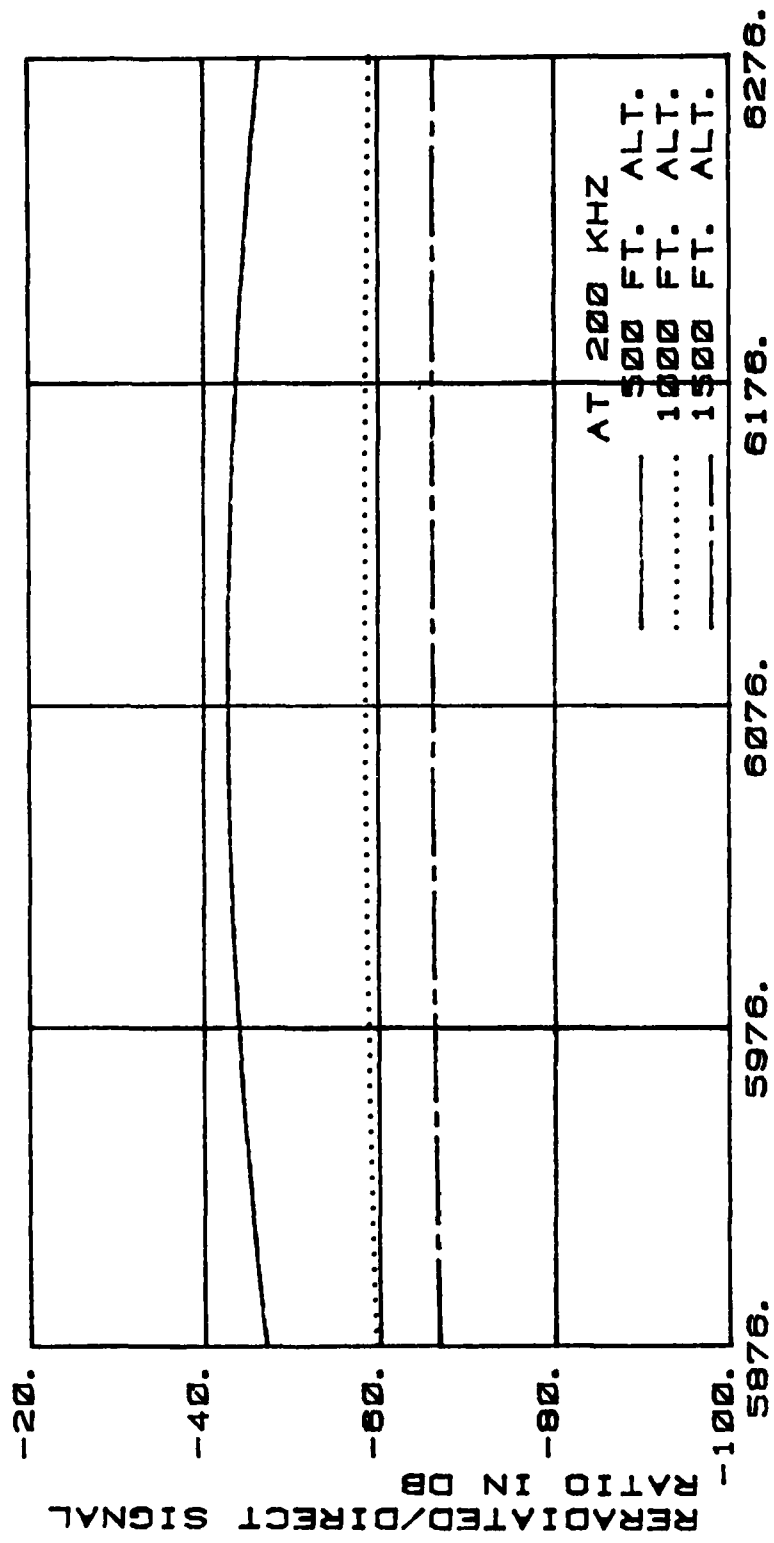


Fig. 4.11e Reradiated/direct signal ratio profile for double steel tower model with cross arms at 200 KHz vs distance from the NDB.

The tower is at 6076 feet (1 N;) and the flight path is directly over the tower.

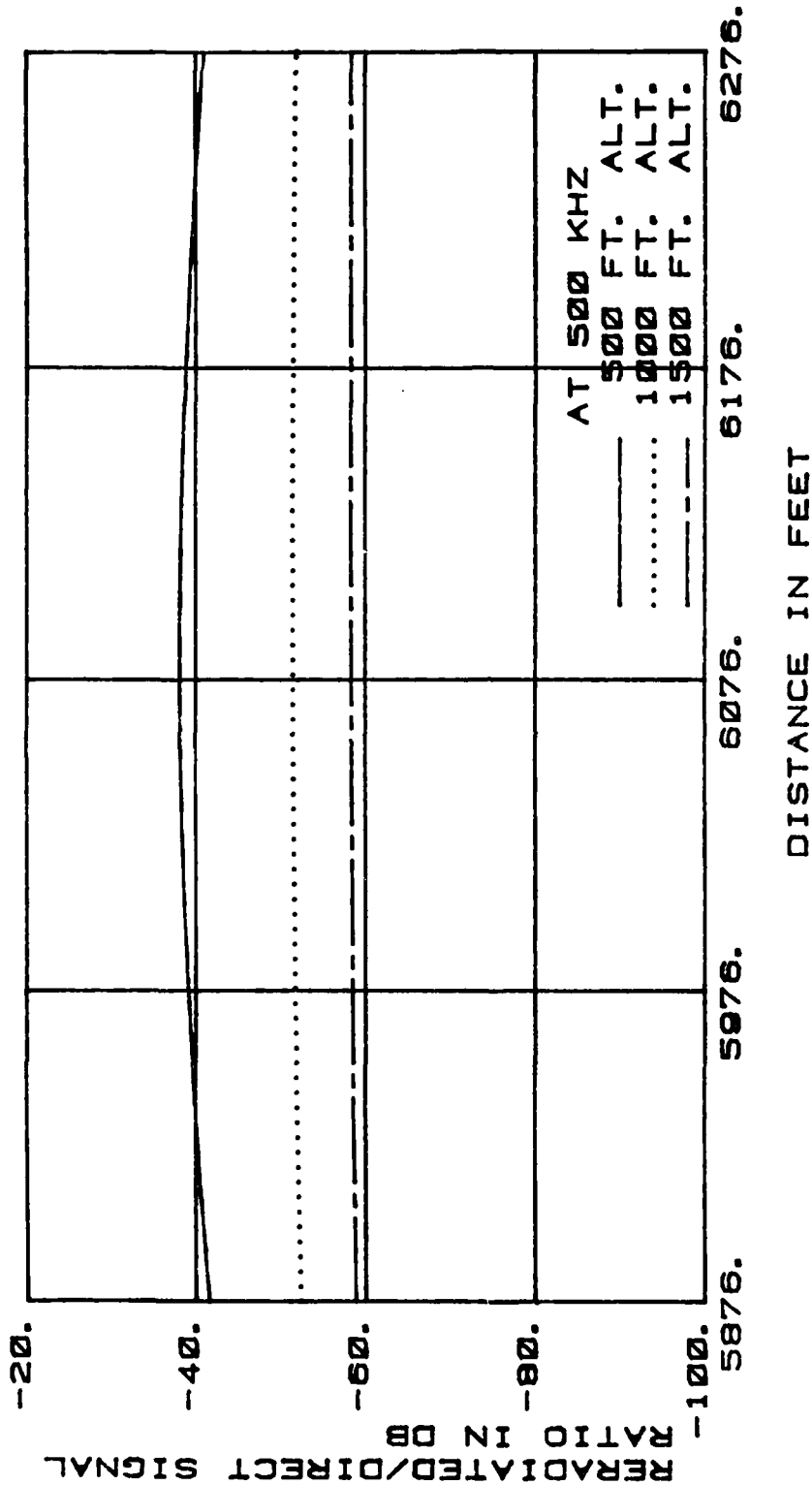


Fig. 4.11f Reradiated/direct signal ratio profile for double steel tower model with cross arms at 500 KHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the tower.

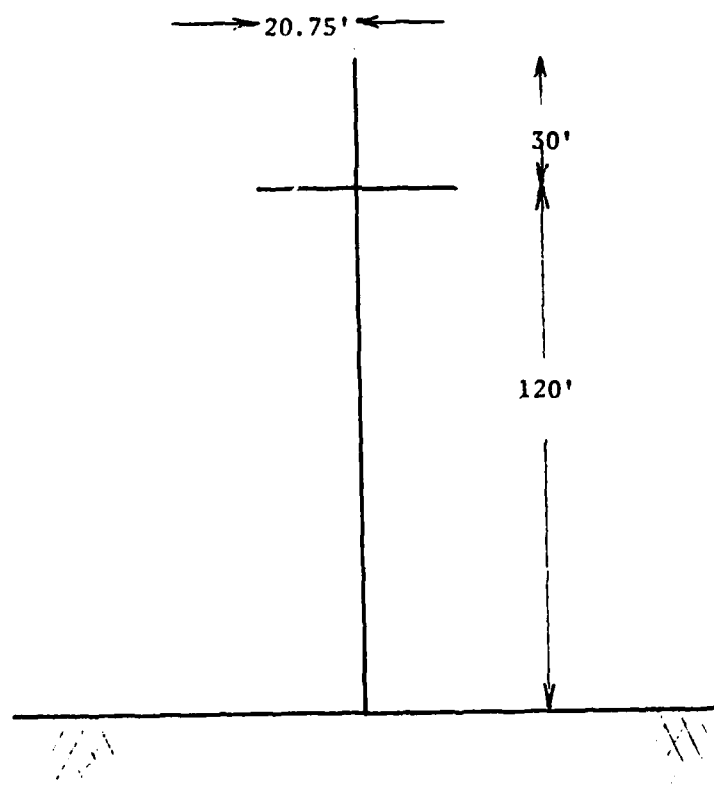


Fig. 4.12 Model of a simple powerline tower, a single steel pole with one cross arm.

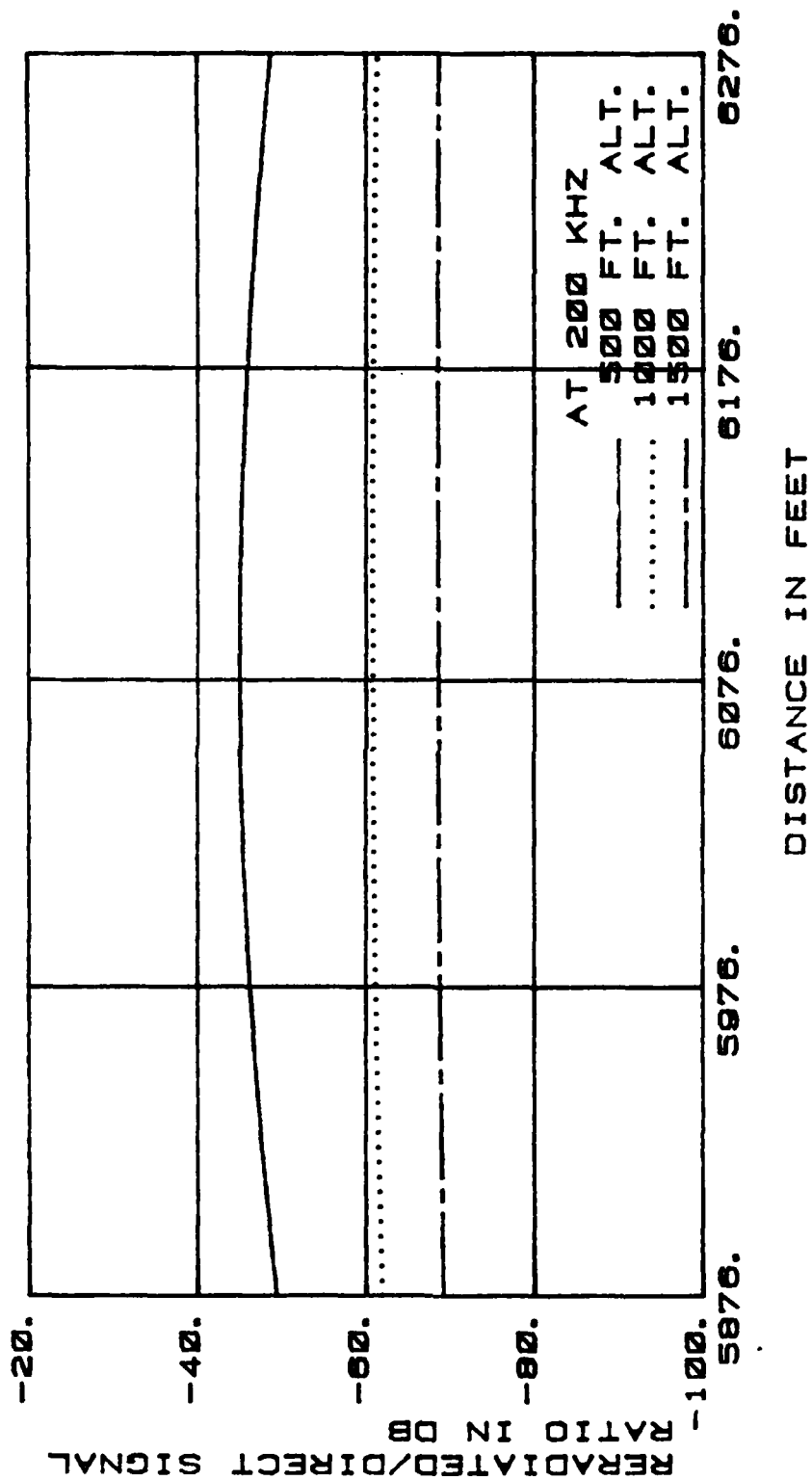


Fig. 4.13a Reradiated/direct signal ratio profile for the simple tower at 200 KHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the tower.

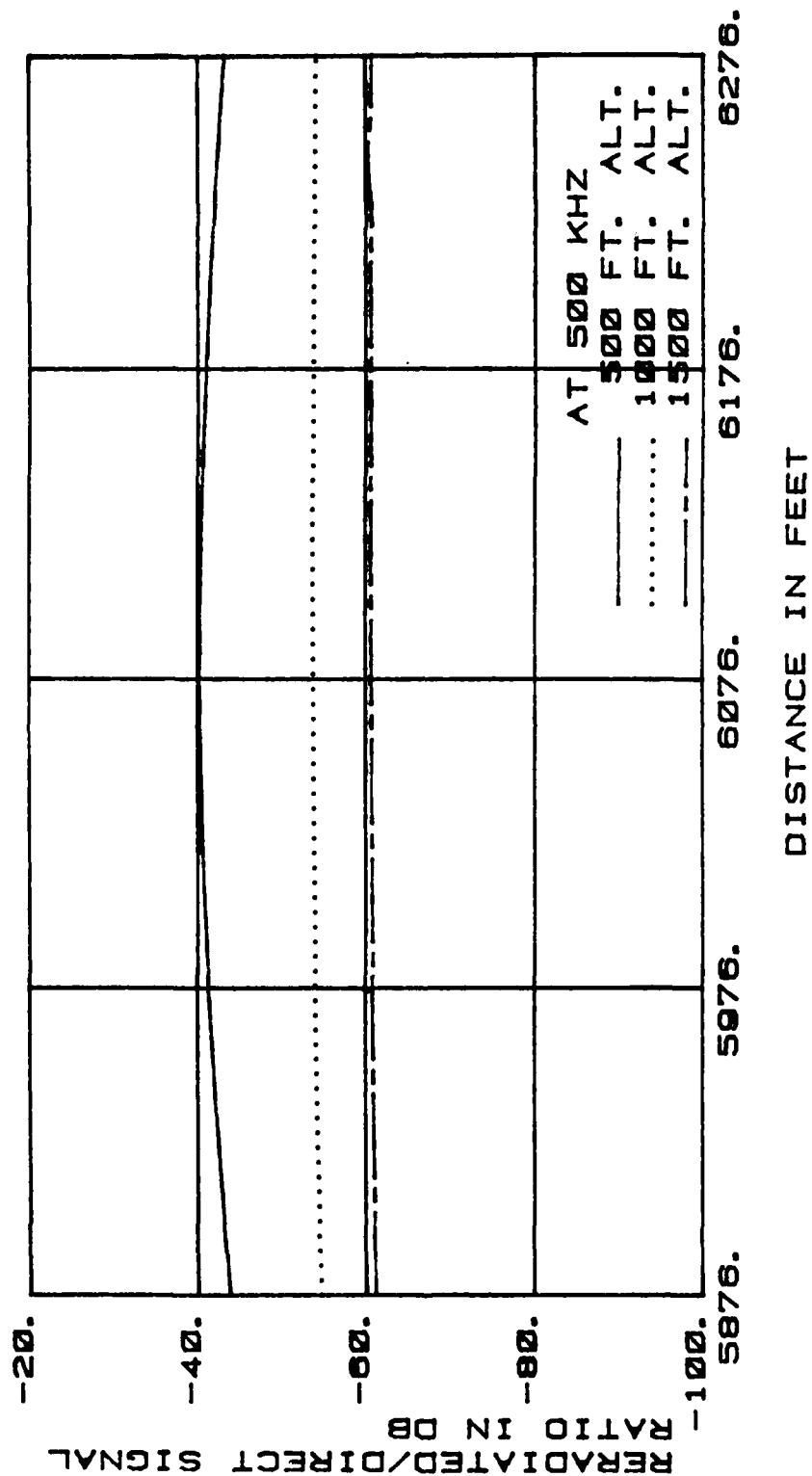


Fig. 4.13b Reradiated/direct signal ratio profile for the simple tower at 500 KHz vs distance from the NDB. The tower is at 6076 feet (1 NDB) and the flight path is directly over the tower.

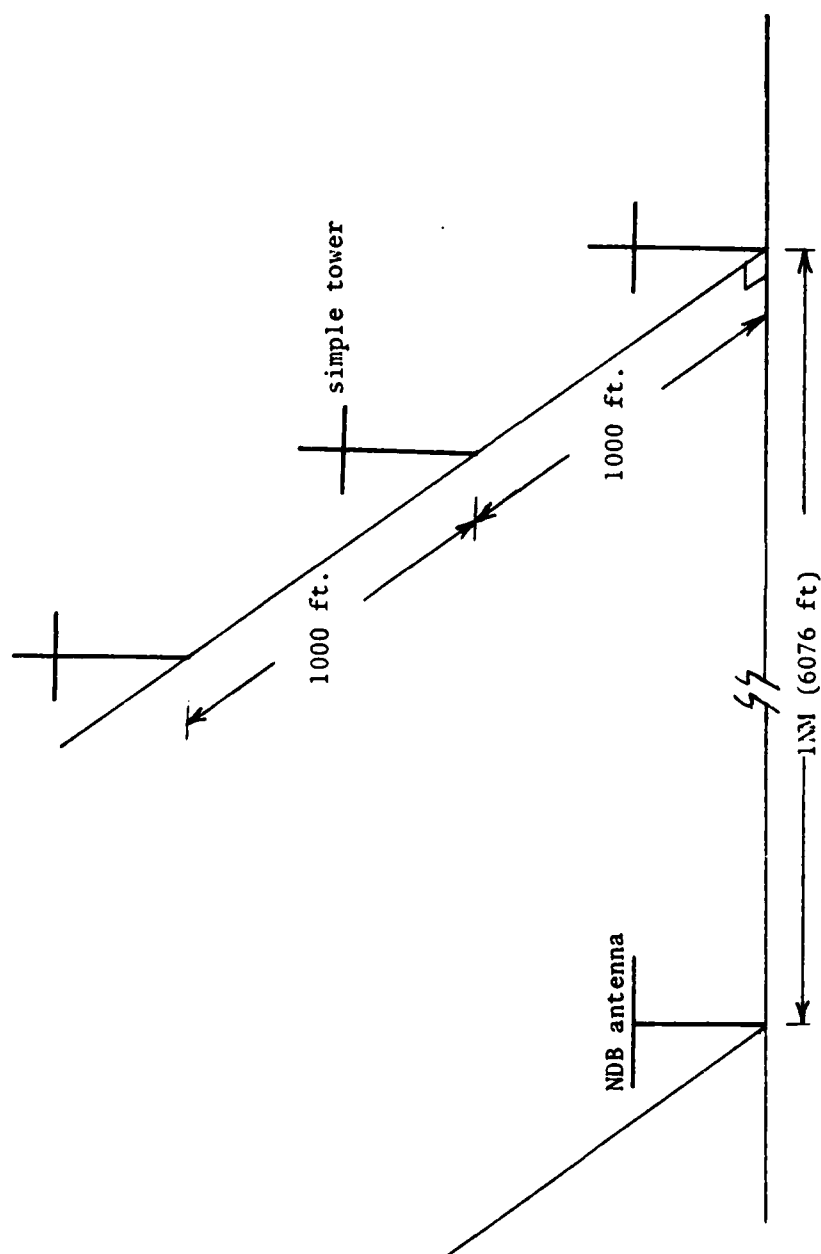


Fig. 4.14 A general layout of three simple tower models with respect to an NDB transmitter.

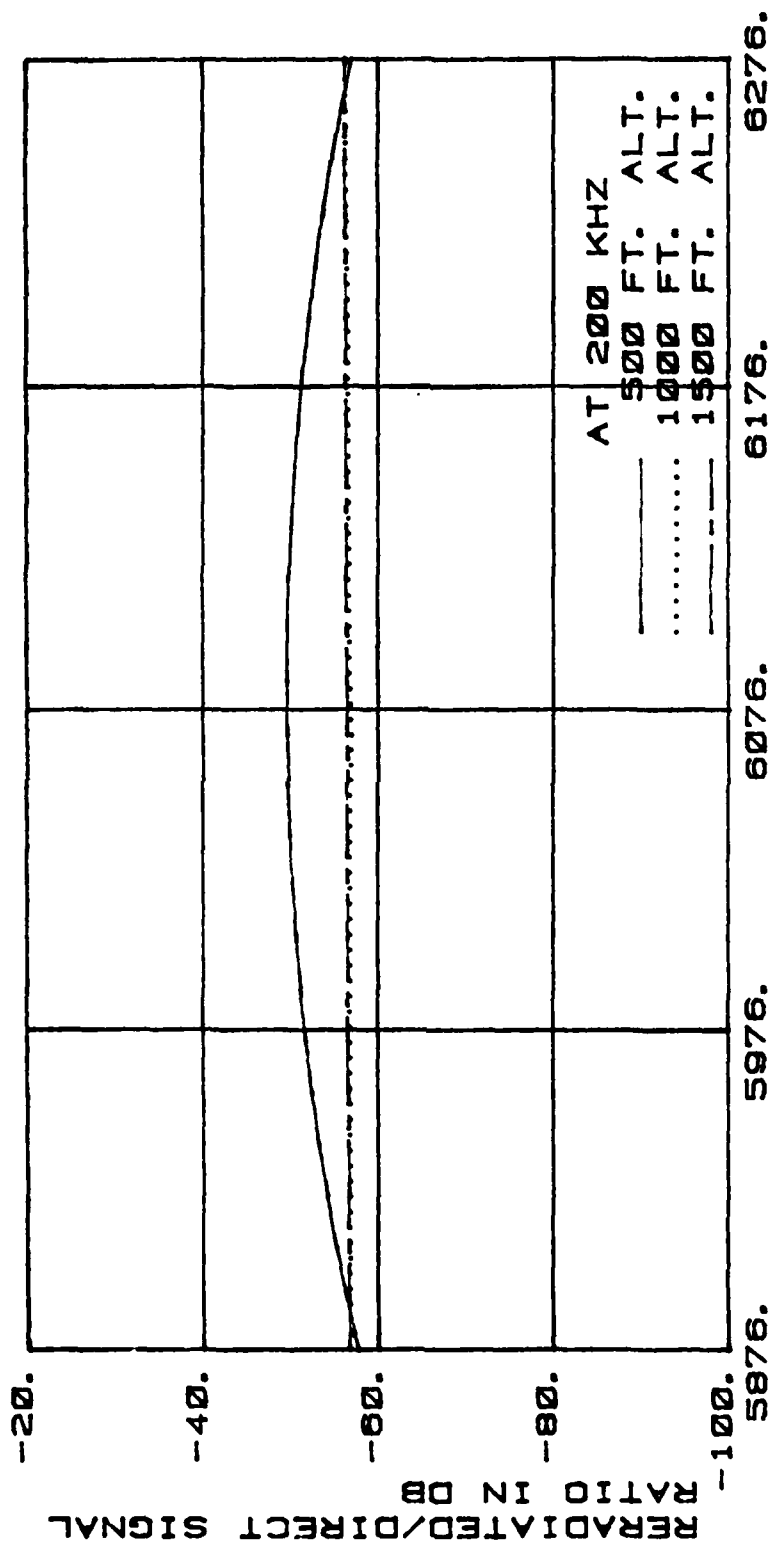


Fig. 4.15a Reradiated/direct signal ratio profile for the three tower model layout at 200 KHz vs distance from the NDB. The tower is 6076 feet (1 Nt) and the flight path is directly over closest tower.

signal ratios are well below the critical value of -15 dB.

Further, possible effects of the horizontal conductors are also investigated. The conductors are modeled as a single eight-inch diameter smooth conductor, spanning 2000 feet across the three simple towers, as shown in Fig. 4.16. The resulting reradiated/direct signal ratio is plotted in Fig. 4.17. As anticipated, the reradiated/direct signal ratios of the horizontal conductor model are much lower compared to those computed for the vertical tower models. The reason is that the vertically-polarized radiated signal from the NDB transmitter reacts minimally with the horizontal conductors.

4.7 Conclusion

The results of Section 4.6 have consistently shown that the reradiated/direct signal ratio is well below the critical value of -15 dB even for flight paths only 500 feet above ground. Thus, it can be concluded that the reradiated signals from powerline structures, line conductors included, should not interfere with normal ADF operation.

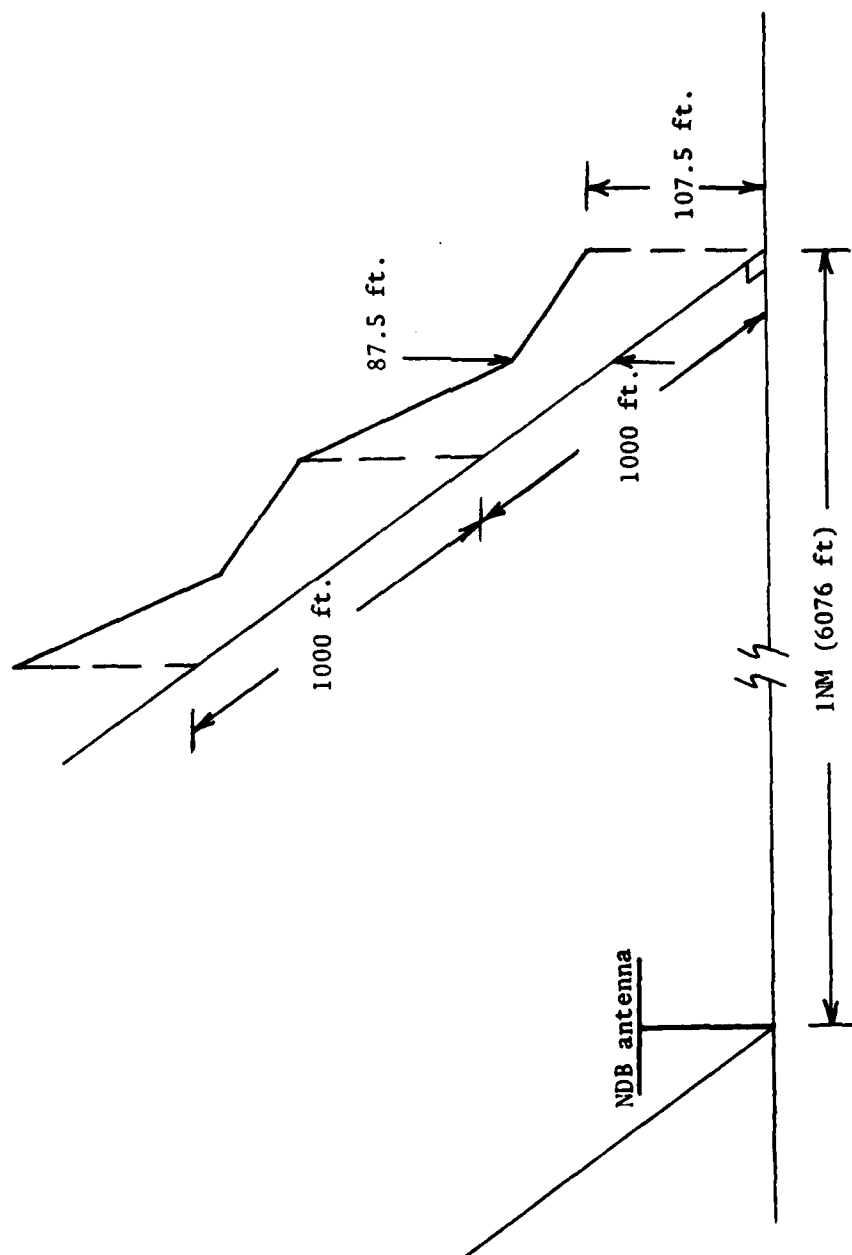


Fig. 4.16 Model of horizontal line conductor spanning across the three towers with respect to an NDB transmitter.

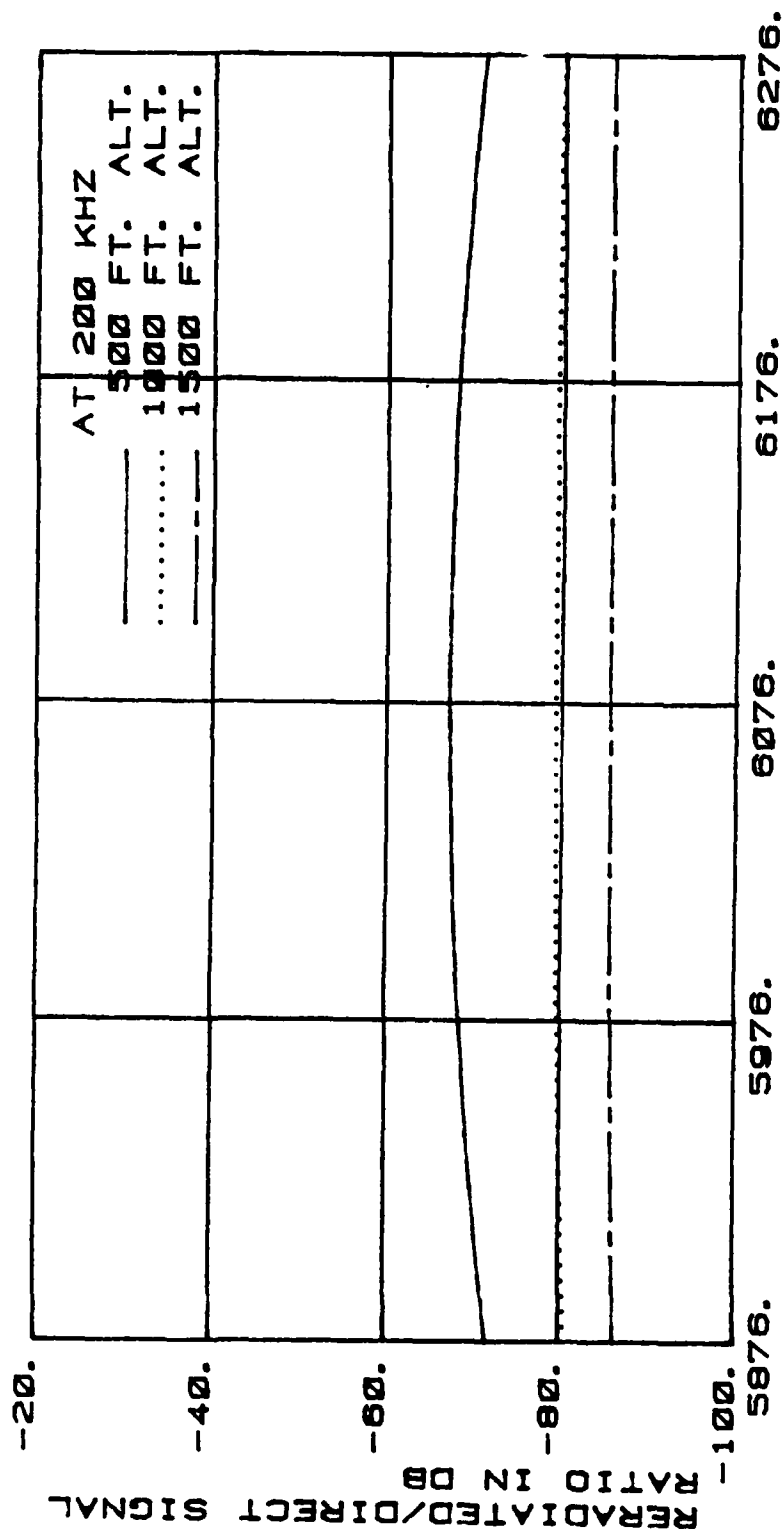


Fig. 4.17a Reradiated/direct signal ratio profile for the horizontal line conductor model at 200 KHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the closest tower.

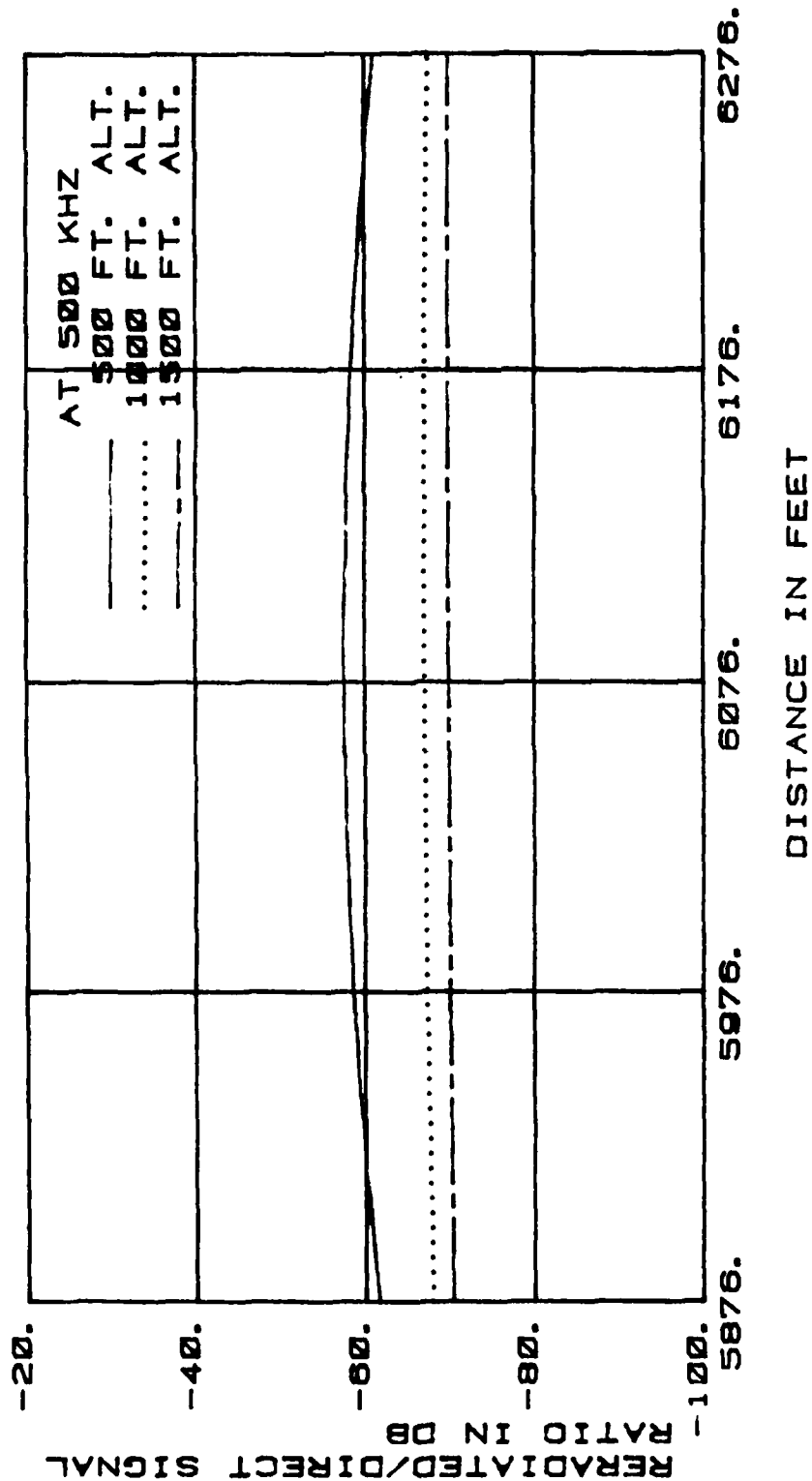


Fig. 4.17b Reradiated/direct signal ratio profile for the horizontal line conductor model at 500 KHz vs distance from the NDB. The tower is 6076 feet (1 NI) and the flight path is directly over the closest tower.

CONCLUSIONS

The objective of this report is to assess the possibilities of harmful interference with ADF operation being caused by electric power transmission lines. The two modes of interference considered are corona radio noise generated actively by the transmission lines, and passive reradiation of the radio signal from the NDB by the transmission line structures.

In order to achieve this objective, computer programs were developed which can predict the critical distance between the aircraft containing the ADF receiver and the power transmission line where the ratio of desired signal to either transmission line noise or reradiated signal is 15 dB. These predictions can be made as a function of the distance separating the NDB transmitter and the powerline, the elevation of the flying aircraft (and hence the ADF receiver), the ERP of the NDB transmitter, the geometry and voltage of the powerline, and the frequency. For the case of generated radio noise, the permittivity and conductivity of the earth can also be varied; however, for the passive reradiation case the earth is assumed to be perfectly conducting.

Regarding active generation of radio noise, AC lines generate considerably more radio noise than do DC lines. However, even for the worst case considered in this study, a 765 kV AC powerline located 20 nautical miles from a 200 kHz NDB, the results show that for an aircraft flying at only a 500 feet altitude, the aircraft if on a path through NDB location and perpendicular to the powerline, would have to approach to less than 4000 feet from the powerline before the ADF signal to noise ratio dropped below 15 dB. The result is for a weather

condition of heavy rain, which causes an AC line to generate the highest level of radio noise. If the NDB is located more closely to the powerline, the radio noise has relatively less effect on ADF performance since the desired NDB signal level is increased while the radio noise level remains unchanged.

Moving the NDB closer to the power transmission structures does, however, increase the likelihood of ADF interference due to passive reradiation of the NDB signal by the powerline structures. The possibility of such interference was estimated using a computer simulation model based on the method of moments. However, even for the worst case considered which had a 500 kHz NDB located one nautical mile from a single steel tower with the aircraft flying over the tower at an altitude of 500 feet, the reradiated signal was calculated to be approximately 38 dB below the level of the directly radiated (desired) signal. The fundamental reason for this is that the wavelength of the NDB signals, even at 500 kHz, is large compared to the tower dimensions.

Thus the conclusion is that locating an NDB near a high voltage transmission line (up to within 1 nautical mile) would probably not impair the function of the NDB due to either corona noise generation or passive reradiation from the line. However, as shown by the worst-case results previously mentioned, there is a possibility of interference for a situation which involves a low power beacon located at a relatively large distance from a potentially interfering power line. And, it should be pointed out that other possible interference mechanisms, such as powerline carrier radiation, have not been considered in this study.

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APPENDICES

APPENDIX A

Derivation for equation of field factor
for point P anywhere in space

Assuming a quasi-static condition, the magnetic fields can be viewed as being produced only from the current through the line conductor. Application of Ampere's law to the current carrying conductor gives the magnetic fields in space around the conductor. This is illustrated in Fig. A-1 below for the magnetic fields at ground level due to corona generated currents in the line conductor.

Using

$$H = \frac{I}{2\pi r} \quad (\text{A-1})$$

then, from Fig. A-1,

$$H_{\ell} = H_i = \frac{I}{2\pi} \cdot \frac{1}{\sqrt{x^2 + h^2}} \quad (\text{A-2})$$

The resultant magnetic field H_R is given by

$$H_R = 2H_{\ell} \cdot \cos \theta \quad (\text{A-3})$$

$$= 2 \cdot \frac{I}{2\pi} \cdot \frac{h}{x^2 + h^2} \quad (\text{A-4})$$

Thus,

$$H_R = \frac{I}{2\pi} \cdot \frac{2h}{x^2 + h^2} \quad (\text{A-5})$$

in magnitude and in the horizontal direction as shown.

Assuming a TEM mode of wave propagation, the corresponding electric field can be obtained by the equation

$$E = Z_0 H \quad (\text{A-6})$$

where Z_0 is the intrinsic impedance of free space and $Z_0 = 120\pi$.

Therefore,

$$H = 120\pi \cdot H_R \quad (\text{A-7})$$

$$= 120 \cdot \frac{I}{2\pi} \cdot \frac{2h}{x^2 + h^2} \quad (\text{A-8})$$

$$= 60 \cdot 1 \cdot \frac{2h}{x^2 + h^2} \quad (A-9)$$

The direction of the electric field is vertical, perpendicular to the magnetic field as shown in Fig. A-1.

Normally, when dealing with magnetic field, it is adequate to consider the line conductor in free space without any image. However, if the earth is assumed perfectly conducting, the image will act to double the field at ground level due to symmetry. In all the sections dealing with powerline conductors in this report, it is assumed that the earth is perfectly conducting and thus fields due to image conductors are also being considered.

For any point in space, as shown in Fig. A-2, the magnetic field due to corona generated currents in the powerline conductor can be determined.

The horizontal component of the magnetic field is given by

$$H_x = H_i \cos \beta - H_\ell \cos \alpha \quad (A-10)$$

$$= \frac{I}{2\pi r_i} \cdot \left(\frac{(h_p + h)}{r_i} \right) - \frac{I}{2\pi r_\ell} \cdot \left(\frac{(h_p - h)}{r_\ell} \right) \quad (A-11)$$

$$= \frac{I}{2\pi} \cdot \left(\frac{h_p + h}{r_i^2} - \frac{h_p - h}{r_\ell^2} \right) \quad (A-12)$$

$$= \frac{I}{2\pi} \cdot \left[\frac{h_p + h}{x^2 + (h_p + h)^2} - \frac{h_p - h}{x^2 + (h_p - h)^2} \right] \quad (A-13)$$

Similarly, the vertical component of the magnetic field is given by

$$H_z = H_\ell \sin \alpha - H_i \sin \beta \quad (A-14)$$

$$= \frac{I}{2\pi r_\ell} \cdot \frac{x}{r_\ell} - \frac{I}{2\pi r_i} \cdot \frac{x}{r_i} \quad (A-15)$$

$$= \frac{Ix}{2\pi} \cdot \frac{1}{r_\ell^2} - \frac{1}{r_i^2} \quad (A-16)$$

$$= \frac{1}{2\pi} \cdot \left(\frac{1}{x^2 + (h_p - h)^2} - \frac{1}{x^2 + (h_p + h)^2} \right) \quad (\text{A-17})$$

thus, the resultant magnetic field is given by

$$H_R = \sqrt{H_x^2 + H_z^2} \quad (\text{A-18})$$

whose direction is as shown in Fig. A-2.

The corresponding electric field is then

$$E = 120\pi \cdot H_R \quad (\text{A-19})$$

$$= 120\pi \cdot \sqrt{H_x^2 + H_z^2} \quad (\text{A-20})$$

$$= 120\pi \cdot \left\{ \left(\frac{1}{2\pi} \right)^2 \cdot \left[\frac{h_p + h}{x^2 + (h_p + h)^2} - \frac{h_p - h}{x^2 + (h_p - h)^2} \right]^2 \right.$$

$$\left. \left(\frac{Ix}{2\pi} \right)^2 \cdot \left[\frac{1}{x^2 + (h_p - h)^2} - \frac{1}{x^2 + (h_p + h)^2} \right]^2 \right\}^{1/2} \quad (\text{A-21})$$

Simplifying equation (A-21) yields

$$E = 60 \cdot I \cdot \left\{ \left[\frac{h_p + h}{x^2 + (h_p + h)^2} - \frac{h_p - h}{x^2 + (h_p - h)^2} \right]^2 \right.$$

$$\left. + x^2 \left[\frac{1}{x^2 + (h_p - h)^2} - \frac{1}{x^2 + (h_p + h)^2} \right]^2 \right\}^{1/2} \quad (\text{A-22})$$

The direction of the electric field is perpendicular to the magnetic field as shown in Fig. A-2. Equation (A-22) can be written as

$$E = I \cdot F \quad (\text{A-23})$$

where F is termed the field factor.

In applying modal analysis for the computation of the RI noise radiated from the 3-phase AC powerlines, the resultant RI noise for each phase is related to the modes by the equation

$$E_{\text{phase}=n} = \sqrt{E_{m=1}^2 + E_{m=2}^2 + E_{m=3}^2} \quad (\text{A-24})$$

where m denotes the mode number and $n = 1, 2$ or 3 . This operation is detailed in section 2.2.

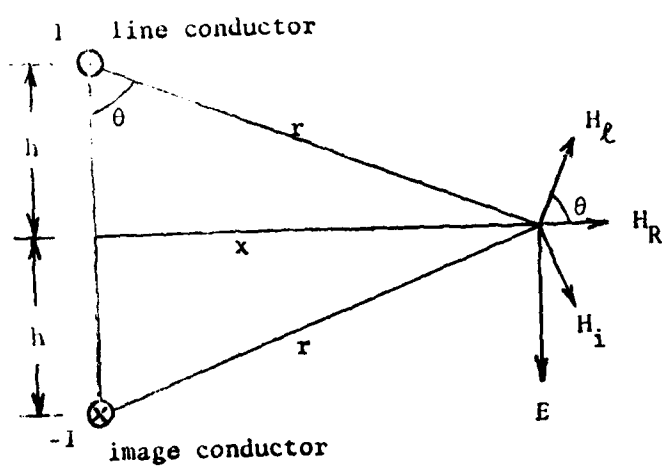


Fig. A-1. Illustration of the magnetic and electric fields at ground level due to current I in a line conductor above a perfectly conducting ground.

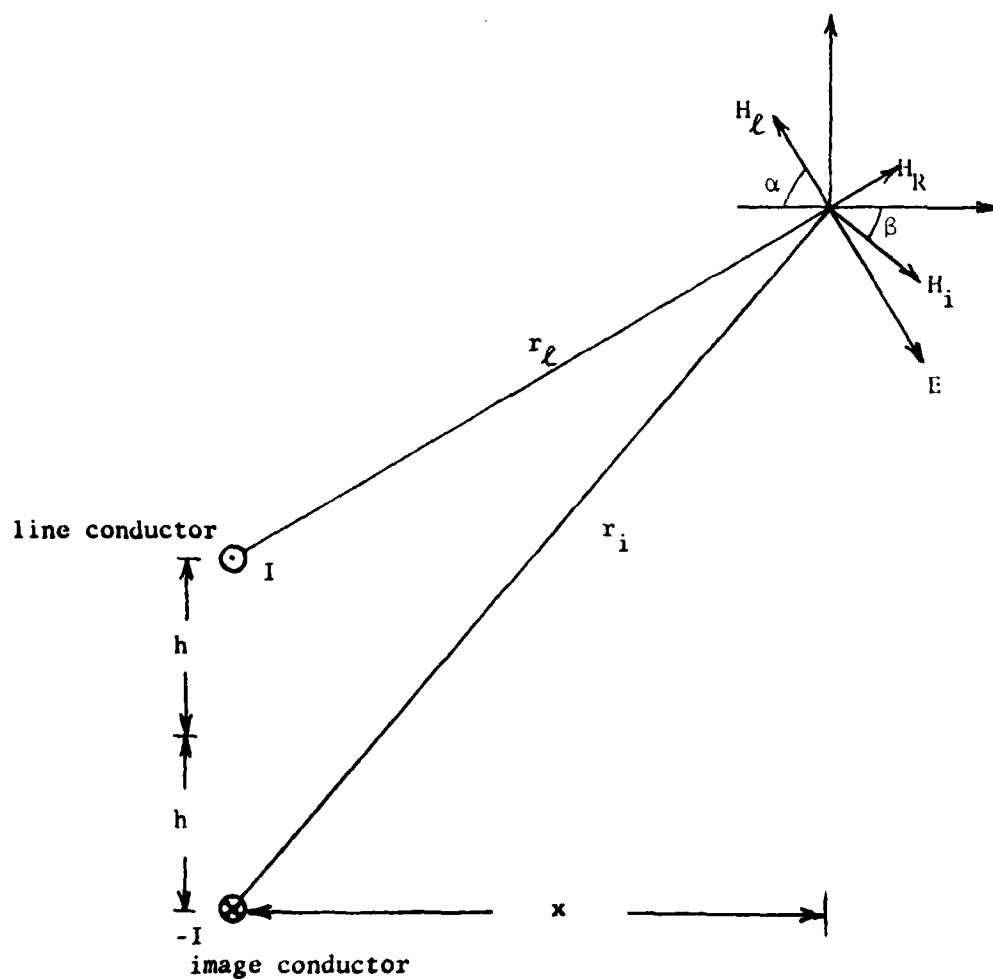


Fig. A-2. Illustration of the magnetic and electric fields at any point in space due to current I in a line conductor above a perfectly conducting ground.

APPENDIX B

Program CHARGE listing for computing the values
of the total charge on each conductor bundle

FILE: CARGE FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

C      DETERMINE THE VALUE OF CHARGE Q ON EACH CONDUCTOR          SAT00010
C      *DOLE*                                                     SAT00020
COMMON /COORDS/ XLOC(100),YLOC(100),YIMAGE(100),GMR(100)      SAT00030
COMMON /INTGRS/ IRD,IWR,NCOND,NPSPP,ISNFLAG,J2,IPIVOT         SAT00040
COMMON /COMPLX/ TRMAT(100,101),V(100)                         SAT00050
COMMON /CONSTS/ CONST,TPK,ZERO,XMIN,XINC                       SAT00060
COMMON /REALS / PMAT(100,100)                                  SAT00070
COMPLEX TRMAT,V,EFIELD,CONST                                  SAT00080
C                                                                    SAT00090
WRITE(5,99)                                                    SAT00100
99  FORMAT('1',T10,'THE INPUT DATA',/)                        SAT00110
READ (5,1) NCOND,XMIN,XINC,NPSPP                               SAT00120
WRITE(6,1) NCOND,XMIN,XINC,NPSPP                                SAT00130
1   FORMAT(14,2F10.3,14)                                        SAT00140
    XMIN = XMIN/3.28                                            SAT00150
    XINC = XINC/3.28                                            SAT00160
    DO 20 I = 1,NCOND                                           SAT00170
      READ(5,2) XLOC(I),YLOC(I),GMR(I),V(I)                    SAT00180
      WRITE(6,2) XLOC(I),YLOC(I),GMR(I),V(I)                    SAT00190
      YLOC(I) = YLOC(I)/3.28                                     SAT00200
      XLOC(I) = XLOC(I)/3.28                                     SAT00210
      GMR(I) = GMR(I)/3.28                                       SAT00220
      YIMAGE(I) = -YLOC(I)                                       SAT00230
20  FORMAT(3F10.3,2E15.5)                                       SAT00240
C      CALL SUBROUTINE THAT                                     SAT00250
C      *DOLE* THAT                                             SAT00260
C      *DOLE* SUBROUTINE CRUNCH                                SAT00270
C      *DOLE* CRUNCH                                           SAT00280
C      *DOLE* SUBROUTINE SWAPRW                                SAT00290
C      *DOLE* SWAPRW                                           SAT00300
C      *DOLE* IS COMPLEX Q ON EACH CONDUCTOR BUNDLE           SAT00310
C                                                                    SAT00320
C      *DOLE* (9)                                              SAT00330
C      *DOLE* (5X,2) COMPLEX Q (COUL/MI) ON EACH CONDUCTOR',/) SAT00340
C      *DOLE* I = 1,NCOND                                        SAT00350
C      *DOLE* (J2) = TRMAT(I,J2)                                SAT00360
20  WRITE(6,11) I,TRMAT(I,J2)                                    SAT00370
11  FORMAT(5X,'J2 (',I1,',')=' ,2(3X,G10.3))                  SAT00380
    XYP                                     SAT00390
    END                                     SAT00400
C                                                                    SAT00410
C      *DOLE* (10) SUBROUTINES                                SAT00420
C      *DOLE* SUBROUTINE THAT                                  SAT00430
C      *DOLE* (COORDS/ XLOC(100),YLOC(100),YIMAGE(100),GMR(100) SAT00440
COMMON /INTGRS/ IRD,IWR,NCOND,NPSPP,ISNFLAG,J2,IPIVOT         SAT00450
COMMON /COMPLX/ TRMAT(100,101),V(100)                         SAT00460
COMMON /CONSTS/ CONST,TPK,ZERO,XMIN,XINC                       SAT00470
COMMON /REALS / PMAT(100,100)                                  SAT00480
COMPLEX TRMAT,V,EFIELD,CONST                                  SAT00490
C                                                                    SAT00500
X = 1./TPK                                                     SAT00510
C                                                                    SAT00520
C      *DOLE* (10) SUBROUTINES                                SAT00530
C      *DOLE* SUBROUTINE THAT                                  SAT00540
C      *DOLE* (10) SUBROUTINES                                SAT00550
C      *DOLE* (10) SUBROUTINES                                SAT00560
C      *DOLE* (10) SUBROUTINES                                SAT00570
C      *DOLE* (10) SUBROUTINES                                SAT00580
C      *DOLE* (10) SUBROUTINES                                SAT00590
C      *DOLE* (10) SUBROUTINES                                SAT00600
C      *DOLE* (10) SUBROUTINES                                SAT00610
C      *DOLE* (10) SUBROUTINES                                SAT00620
C      *DOLE* (10) SUBROUTINES                                SAT00630
C      *DOLE* (10) SUBROUTINES                                SAT00640
C      *DOLE* (10) SUBROUTINES                                SAT00650
C      *DOLE* (10) SUBROUTINES                                SAT00660
C      *DOLE* (10) SUBROUTINES                                SAT00670
C      *DOLE* (10) SUBROUTINES                                SAT00680
C      *DOLE* (10) SUBROUTINES                                SAT00690
C      *DOLE* (10) SUBROUTINES                                SAT00700
C      *DOLE* (10) SUBROUTINES                                SAT00710
C      *DOLE* (10) SUBROUTINES                                SAT00720
C      *DOLE* (10) SUBROUTINES                                SAT00730
C      *DOLE* (10) SUBROUTINES                                SAT00740
C      *DOLE* (10) SUBROUTINES                                SAT00750
C      *DOLE* (10) SUBROUTINES                                SAT00760
C      *DOLE* (10) SUBROUTINES                                SAT00770
C      *DOLE* (10) SUBROUTINES                                SAT00780
C      *DOLE* (10) SUBROUTINES                                SAT00790
C      *DOLE* (10) SUBROUTINES                                SAT00800
C      *DOLE* (10) SUBROUTINES                                SAT00810
C      *DOLE* (10) SUBROUTINES                                SAT00820
C      *DOLE* (10) SUBROUTINES                                SAT00830
C      *DOLE* (10) SUBROUTINES                                SAT00840
C      *DOLE* (10) SUBROUTINES                                SAT00850
C      *DOLE* (10) SUBROUTINES                                SAT00860
C      *DOLE* (10) SUBROUTINES                                SAT00870
C      *DOLE* (10) SUBROUTINES                                SAT00880
C      *DOLE* (10) SUBROUTINES                                SAT00890
C      *DOLE* (10) SUBROUTINES                                SAT00900
C      *DOLE* (10) SUBROUTINES                                SAT00910
C      *DOLE* (10) SUBROUTINES                                SAT00920
C      *DOLE* (10) SUBROUTINES                                SAT00930
C      *DOLE* (10) SUBROUTINES                                SAT00940
C      *DOLE* (10) SUBROUTINES                                SAT00950
C      *DOLE* (10) SUBROUTINES                                SAT00960
C      *DOLE* (10) SUBROUTINES                                SAT00970
C      *DOLE* (10) SUBROUTINES                                SAT00980
C      *DOLE* (10) SUBROUTINES                                SAT00990
C      *DOLE* (10) SUBROUTINES                                SAT01000

```

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```

      VAR=X*ALOG((YLOC(I)-YIMAGE(I))/GMR(I))
      PMAT(I,I) = VAR
      TRMAT(I,I) = CMPLX(VAR,0.)
5
C
      NCONK = NCOND-1
      DO 10 I = 1,NCONK
      L = I+1
      DO 10 J = L,NCONK
      DIST1=SQRT((YLOC(I)-YLOC(J))**2+(XLOC(I)-XLOC(J))**2)
      DIST2=SQRT((YLOC(I)-YIMAGE(J))**2+(XLOC(I)-XLOC(J))**2)
      VAR = X*ALOG(DIST2/DIST1)
      TRMAT(I,J) = CMPLX(VAR,0.)
      PMAT(I,J) = VAR
      PMAT(J,I) = VAR
10  TRMAT(J,I) = TRMAT(I,J)
      RETURN
      END

C
      SUBROUTINE CRUNCH
      COMMON /CONDORS/ XLOC(100),YLOC(100),YIMAGE(100),GMR(100)
      COMMON /INTGRS/ IRD,IWR,NCOND,NPSPP,ISNFLAG,J2,PIVOT
      COMMON /COMPLX/ TRMAT(100,101),V(100)
      COMMON /CONSTS/ CONST,TPIK,ZERO,XMIN,XINC
      COMMON /REALS/ PMAT(100,100)
      COMMON /TRMAT,V,FFIELD,CONST
C
      J2 = NCOND+1
C
      RETURN VLS
C
C
      DO 555 I = 1,NCOND
      TRMAT(I,J2) = V(I)
555
C
      BEGIN GAUSS-JORDAN ELIMINATION
      DO 101 IPIVOT= 1,NCOND
      IF (ICABS(TRMAT(IPIVOT,IPIVOT)) .LE. ZERO) CALL SWAPRW
      IF (ISNFLAG) 98,99,98
      DO 102 IROW = 1,NCOND
      IF (IROW.EQ.IPIVOT) GO TO 102
      IF (ICABS(TRMAT(IROW,IPIVOT)/TRMAT(IPIVOT,IPIVOT)) .LE. ZERO)
      > GO TO 102
      CONST = -TRMAT(IROW,IPIVOT)/TRMAT(IPIVOT,IPIVOT)
      DO 100 ICOL = 1,J2
      TRMAT(IROW,ICOL)=TRMAT(IROW,ICOL)+CONST*TRMAT(IPIVOT,ICOL)
100  CONTINUE
102  CONTINUE
101  CONTINUE
      DO 105 IROW = 1,NCOND
      CONST=TRMAT(IROW,IROW)
      TRMAT(IROW,J2)= TRMAT(IROW,J2)/CONST
105  CONTINUE
      RETURN
      WRITE(6,255)
255  FORMAT(1H1,'TRANSMISSION MATRIX IS SINGULAR,EXECUTION',
      > 'TERMINATING')
      CALL EXIT
      END

```

SAT00560
 SAT00570
 SAT00580
 SAT00590
 SAT00600
 SAT00610
 SAT00620
 SAT00630
 SAT00640
 SAT00650
 SAT00660
 SAT00670
 SAT00680
 SAT00690
 SAT00700
 SAT00710
 SAT00720
 SAT00730
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 SAT00970
 SAT00980
 SAT00990
 SAT01000
 SAT01010
 SAT01020
 SAT01030
 SAT01040
 SAT01050
 SAT01060
 SAT01070
 SAT01080
 SAT01090
 SAT01100

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C	SUBROUTINE SWAPRW	SAT01110
	COMMON /COORDS/ XLOC(100),YLOC(100),YIMAGE(100),GMR(100)	SAT01120
	COMMON /INTGRS/ IRD,IWR,NCOND,NPSP,ISNFLG,J2,IPIVOT	SAT01130
	COMMON /COMPLX/ TRMAT(100,101),V(100)	SAT01140
	COMMON /CONSTS/ CONST,TPIK,ZERO,XMIN,XINC	SAT01150
	COMMON /REALS / PMAT(100,100)	SAT01160
	COMPLEX TRMAT,V,EFIELD,CONST	SAT01170
C		SAT01180
C	VARIABLE 'FIXIT' IS USED ONLY IN SUBROUTINE SWAPRW.	SAT01190
C		SAT01200
	COMPLEX FIXIT	SAT01210
	IF (IPIVOT.EQ.NCOND) GO TO 1	SAT01220
	IRWSW = IPIVOT + 1	SAT01230
3	IF (ICASE(TRMAT(IRWSW,IPIVOT))).LE.ZERO) GO TO 2	SAT01240
	DO 4 ICOLSW = 1,J2	SAT01250
	FIXIT = TRMAT(IPIVOT,ICOLSW)	SAT01260
	TRMAT(IPIVOT,ICOLSW) = TRMAT(IRWSW,ICOLSW)	SAT01270
	TRMAT(IRWSW,ICOLSW) = FIXIT	SAT01280
4	CONTINUE	SAT01290
	RETURN	SAT01300
2	IF (IRWSW.EQ.NCOND) GO TO 1	SAT01310
	IRWSW = IRWSW + 1	SAT01320
	GO TO 3	SAT01330
1	ISNFLG = 1	SAT01340
	RETURN	SAT01350
	END	SAT01360
	BLOCK DATA	SAT01370
	COMMON /COORDS/ XLOC,YLOC,YIMAGE,GMR	SAT01380
	COMMON /INTGRS/ IRD,IWR,NCOND,NPSP,ISNFLG,J2,IPIVOT	SAT01390
	COMMON /COMPLX/ TRMAT,V,EFIELD	SAT01400
	COMMON /CONSTS/ CONST,TPIK,ZERO,XMIN,XINC	SAT01410
	COMMON /REALS / EMAG,XSCAN,PMAT	SAT01420
	REAL XLOC(100)/100*0./,YLOC(100)/100*0./,YIMAGE(100)/100*0./	SAT01430
	REAL PMAT(100,100)/10000*0./	SAT01440
	REAL GMR(100)/100*0./	SAT01450
	COMPLEX TRMAT(100,101)/10100*(0.,0.)/, V(100)/100*(0.,0.)/	SAT01460
	DATA IRD,IWR,NCOND,NPSP,ISNFLG,J2,IPIVOT /5,6,0,0,0,0,0/	SAT01470
	COMPLEX CONST/(0.,0.)/	SAT01480
	DATA TPIK,ZERO,XMIN,XINC/5.5606E-11,.000001,0.,0./	SAT01490
	END	SAT01500
		SAT01510

F. J. ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

C      TO COMPUTE THE LEVEL OF RADIO INTERFERENCE NOISE FROM THE AC      ACR00010
C      TRANSMISSION LINES BY USING MODAL ANALYSIS METHOD                ACR00020
C                                                                           ACR00030
C      THE LATERAL DISTANCE BEGINS AT THE CENTER PHASE                  ACR00040
C                                                                           ACR00050
C      DIMENSION EMAX(50),TAU(50)                                         ACR00060
C      DIMENSION G(30,30),G1(30,30),DM(30,30),DH(30,30),HT(30),HI(30)   ACR00070
C      DIMENSION ZI(30,30),GM(30,30),ALPHA(30)                           ACR00080
C      REAL LAM(20),M(30,30),MI(30,30),JC(20,20),JC2(20,20),JC5(20,20)  ACR00090
C      REAL IC21(20,20),IC51(20,20)                                       ACR00100
C      REAL IC22(20,20),IC52(20,20)                                       ACR00110
C      REAL IC23(20,20),IC53(20,20)                                       ACR00120
C      REAL IP(20,20),IP21(20,20),IP51(20,20)                            ACR00130
C      REAL IP22(20,20),IP52(20,20)                                       ACR00140
C      REAL IP23(20,20),IP53(20,20)                                       ACR00150
C      COMPLEX Q(50)                                                       ACR00160
C      DIMENSION Y(400),X(400),YL(12),XL(12)                             ACR00170
C      DATA YL/'R','I','I','N','D','S','E',' ',' ','D','R'/'          ACR00180
C      DATA XL/'D','I','S','T','A','N','C','E',' ','F','T','/'          ACR00190
C      DATA PI, EPSLN/3.14159,8.854E-12/                                ACR00200
C      DATA EPSI, SIGMA, ERP, C/10.00,0.0100,0.50,3.0E8/               ACR00210
C                                                                           ACR00220
54      WRITE (6,54)                                                       ACR00230
C      FORMAT('10, 'T10, 'N', T16, 'KV', T26, 'HT', T36, 'D', T46, 'RAD', T55, 'RRAD') ACR00240
C      READ (5,1) N,V,H,D,RAD,A                                           ACR00250
1      FORMAT('10,5F10.3)                                                 ACR00260
C      WRITE (6,1) N,V,H,D,RAD,A                                          ACR00270
C      READ (5,2) (Q(I), I=1,3)                                           ACR00280
2      FORMAT('2E15.3)                                                    ACR00290
C      WRITE (6,52)                                                         ACR00300
52      FORMAT('0',5X, 'VALUES OF CHARGE (Q/M) ON EACH CONDUCTOR')       ACR00310
C      WRITE (6,2) (Q(I), I=1,3)                                           ACR00320
C                                                                           ACR00330
C      TO DETERMINE THE MAXIMUM BUNDLE GRADIENT FOR EACH PHASE           ACR00340
C      WRITE (6,50)                                                         ACR00350
50      FORMAT('0',5X, 'VALUES OF MAXIMUM BUNDLE GRADIENT')              ACR00360
C      NN = N-1                                                            ACR00370
C      DO 10 I=1,3                                                         ACR00380
C      RFD = (FLOAT(N)*RAD*(1+NN))**((1/N))                               ACR00390
C      EAVE = CABS(Q(I))/((2.00*PI*EPSLN*FLOAT(N)*RAD*1.00E3))             ACR00400
C      EMAX(I) = EAVE*(1.00+(FLOAT(NN)*RAD/A))                             ACR00410
C      WRITE(6,3) I, EMAX(I)                                               ACR00420
3      FORMAT('10X, 'EMAX ('I,11,') ='F10.3,2X, 'KV/CM')               ACR00430
10     CONTINUE                                                            ACR00440
C                                                                           ACR00450
C      TO DETERMINE THE EXCITATION FUNCTION (TAU) OF EACH PHASE          ACR00460
C      UNDER HEAVY RAIN CONDITION                                         ACR00470
C      WRITE (6,51)                                                         ACR00480
51      FORMAT('0',5X, 'VALUES OF EXCITATION FUNCTION')                 ACR00490
C      IF(N.EQ.1) KN = 7                                                  ACR00500
C      IF(N.EQ.2) KN = 2                                                  ACR00510
C      IF(N.GE.3) KN = 0                                                  ACR00520
C      DIA = 2.00*RAD                                                      ACR00530
C      DO 20 I = 1,3                                                       ACR00540
C      TAUDR = 78.00-(590.00/EMAX(I))+38.00*ALOG10(DIA/3.80)+FLOAT(KN)  ACR00550

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FILE: ACR FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

      RAT = TAUDR/20.00
      TAU(1) = (10.00**RAT)
      WRITE (6,4) I,TAU(1)
      FORMAT(10X,'TAU ('',I1,'') =',F10.3,2X,'MICROAMP/SQRT M')
4      CONTINUE
20
C
C      TO DETERMINE THE 'GEOMETRIC MATRIX' OF THE PHASES
C      WRITE (6,53)
53      FORMAT('0',5X,'VALUES OF GEOMETRIC MATRIX (G)')
      DO 30 I = 1,3
      HT(I) = H
      HT(I) = -H
      DO 30 J = 1,3
      IF(I.EQ.J) GO TO 31
      DW(I,J) = 0
      IF(I.EQ.1.AND.J.EQ.3) DW(I,J) = 0*2.00
      IF(I.EQ.3.AND.J.EQ.1) DW(I,J) = 0*2.00
      DW(I,J) = SQRT((HT(I) HT(I))**2 + DW(I,J)**2)
      G(I,J) = ALOG(DW(I,J)/DW(1,1))
      GO TO 30
31      G(I,J) = ALOG(2.00*HT(I)*100.00/A)
30      CONTINUE
      WRITE (6,5) ((G(I,J),J=1,3),I=1,3)
      FORMAT(3(5X,F10.3))
C
C      TO DETERMINE THE 'MODAL TRANSFORMATION MATRIX' OF THE PHASES
C      NEED TO COMPUTE THE VALUES OF LAMBDA WHERE LAMBDA ARE THE CURIC
C      ROOTS FOR THE DETERMINANT OF 'GEOMETRIC MATRIX' EQUAL ZERO
C      * G11-LAM      G12      G13      *
C      * G21      G22-LAM  G23      * = 0.0      (A)
C      * G31      G32      G33-LAM *
C
C      OBTAIN THE CURIC EQUATION AND SOLVE FOR LAMBDA (LAM)
C      THE CURIC EQUATION IS OF THE FORM
C      LAM(CURE)+A1*LAM(SQ)+A2*LAM+A3 = 0.0
C      TO SOLVE FOR LAMBDA
C      WRITE (6,55)
55      FORMAT('0',5X,'VALUES OF LAMBDA')
C
      A1 = -(G(1,1) + G(2,2) + G(3,3))
      A2 = (G(1,1)*G(2,2) + G(1,1)*G(3,3) + G(2,2)*G(3,3)) -
      / (G(1,2)*G(2,1) + G(3,2)*G(2,3) + G(1,3)*G(3,1))
      A3 = (G(1,1)*G(3,2)*G(2,3) + G(1,2)*G(2,1)*G(3,3) +
      2      G(1,3)*G(3,1)*G(2,2)) - (G(1,1)*G(2,2)*G(3,3) +
      3      G(1,2)*G(3,1)*G(2,3) + G(1,3)*G(2,1)*G(3,2))
C
      QQ = (1.00*A2 - A1*A1)/9.00
      R = (9.00*A1*A2 - 27.00*A3 - 2.00*(A1**3))/54.00
      THETA = ARCCOS(R/SQRT(-QQ))
      DO 40 I = 1,3
      LAM(I) = 2.00*SQRT(-QQ)*COS((THETA/3.00)+(FLOAT(I)-1.00)*120.00*
      2      PI/180.00)-A1/3.00
      WRITE (6,7) I,LAM(I)
      FORMAT(10X,'LAM ('',I1,'') =',F10.3)
7      CONTINUE
40

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ACR00560
 ACR00570
 ACR00580
 ACR00590
 ACR00600
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 ACR00670
 ACR00680
 ACR00690
 ACR00700
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 ACR00970
 ACR00980
 ACR00990
 ACR01000
 ACR01010
 ACR01020
 ACR01030
 ACR01040
 ACR01050
 ACR01060
 ACR01070
 ACR01080
 ACR01090
 ACR01100

FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

C
C      TO ARRANGE THE VALUES OF LAMBDA'S IN ASCENDING ORDER
C      WRITE (6,56)
56      FORMAT('0',5X,'VALUES OF LAMBDA'S IN ASCENDING ORDER')
      I = 3
      NN = I-1
      DO 60 K = 1,NN
      JJ = I-K
      DO 70 L = 1,JJ
      IF(LAM(L).LE.LAM(L+1)) GO TO 70
      TEMP = LAM(L)
      LAM(L) = LAM(L+1)
      LAM(L+1) = TEMP
70      CONTINUE
60      CONTINUE
      WRITE (6,8) (I,LAM(I),I=1,3)
8      FORMAT(10X,'LAM ('',I1,'') =',F10.3)
C
C      SUBSTITUTING EACH OF THESE VALUES OF LAMBDA'S INTO EQUATION (A)
C      WILL GIVE US THE COLUMN OF THE 'MODAL TRANSFORMATION MATRIX' (M)
C      WRITE (5,57)
57      FORMAT('0',5X,'VALUES OF MODAL TRANSFORMATION MATRIX (M)')
C      FOR FIRST COLUMN
      DO 80 I = 1,3
80      G(I,1) = G(I,1) - LAM(I)
      M(I,1) = 1.00
      M(2,1) = M(I,1)
      M(2,1) = -(G(I,1)*M(I,1) + G(I,3)*M(3,1))/G(I,2)
      DIV1 = SQRT(M(I,1)**2 + M(2,1)**2 + M(3,1)**2)
      DO 81 I = 1,3
81      M(I,1) = M(I,1)/DIV1
C
C      FOR SECOND COLUMN
      DO 998 I = 1,3
998      G(I,1) = G(I,1) + LAM(I) - LAM(2)
      M(I,2) = -1.00
      M(3,2) = -M(I,2)
      M(2,2) = -(G(I,1)*M(I,2) + G(I,3)*M(3,2))/G(I,2)
      DIV2 = SQRT(M(I,2)**2 + M(2,2)**2 + M(3,2)**2)
      DO 997 I = 1,3
997      M(I,2) = M(I,2)/DIV2
C
C      FOR THIRD COLUMN
      DO 82 I = 1,3
82      G(I,1) = G(I,1) + LAM(2) - LAM(3)
      M(I,3) = 1.00
      M(3,3) = M(I,3)
      M(2,3) = -(G(I,1)*M(I,3) + G(I,3)*M(3,3))/G(I,2)
      DIV3 = SQRT(M(I,3)**2 + M(2,3)**2 + M(3,3)**2)
      DO 83 I = 1,3
83      M(I,3) = M(I,3)/DIV3
C
C      WRITE (4,9) ((M(I,J),J=1,3),I=1,3)
9      FORMAT(3(5X,F10.3))
C

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ACRO1110
 ACRO1120
 ACRO1130
 ACRO1140
 ACRO1150
 ACRO1160
 ACRO1170
 ACRO1180
 ACRO1190
 ACRO1200
 ACRO1210
 ACRO1220
 ACRO1230
 ACRO1240
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 ACRO1300
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 ACRO1490
 ACRO1500
 ACRO1510
 ACRO1520
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 ACRO1540
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 ACRO1560
 ACRO1570
 ACRO1580
 ACRO1590
 ACRO1600
 ACRO1610
 ACRO1620
 ACRO1630
 ACRO1640
 ACRO1650

FILE: ACR1 FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

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C      STEP 5
C      TO DETERMINE THE MODAL COMPONENTS OF CORONA CURRENT INJECTIONS
C      NEED TO FIND THE INVERSE MATRICES OF (G) AND (M)
C
C      TO FIND INVERSE MATRIX OF (G) I.E. (GI)
C      WRITE (6,58)
58      FORMAT('0',5X,'VALUES OF INVERSE MATRIX OF (G)')
      DO 94 I = 1,3
94      G(I,1) = G(I,1) + LAM(3)
      K = 1
      CALL INVERS (K,G,M,ZI)
      DO 90 J = 1,3
      DO 90 I = 1,3
90      G(I,J) = ZI(I,J)
      WRITE (6,12) ((G(I,J),J=1,3),I=1,3)
C
C      TO FIND INVERSE MATRIX OF (M) I.E. (MI)
C      WRITE (6,59)
59      FORMAT('0',5X,'VALUES OF INVERSE MATRIX OF (M)')
      K = 2
      CALL INVERS (K,G,M,ZI)
      DO 91 J = 1,3
      DO 91 I = 1,3
91      MI(I,J) = ZI(I,J)
      WRITE (6,12) ((MI(I,J),J=1,3),I=1,3)
12      FORMAT(3(5X,F10.3))
C
C      TO OBTAIN THE PRODUCT OF (GI)*(MI)
C      WRITE (6,61)
61      FORMAT('0',5X,'VALUES OF PRODUCT OF (MI)*(GI)')
      DO 92 I = 1,3
      DO 92 J = 1,3
      GM(I,J) = 0.0
      DO 92 INDEX = 1,3
      GM(I,J) = GM(I,J) + MI(I,INDEX)*GI(INDEX,J)
92      CONTINUE
      WRITE (6,12) ((GM(I,J),J=1,3),I=1,3)
C
C      *****
C      COMPUTATION FOR PHASE ONE ONLY
C      *****
C
C      TO OBTAIN THE VALUES OF THE CORONA CURRENT INJECTION JC ON
C      PHASE ONE
C      WRITE (6,14)
14      FORMAT('0',5X,'VALUES OF CORONA CURRENT IN EACH MODE')
      DO 93 I = 1,3
93      JC(I,1) = GM(I,1)*TAU(1)
      WRITE (6,99) (JC(I,1),I=1,3)
99      FORMAT(15X,F10.3)
C
C      TO DETERMINE THE MODAL CURRENTS IN THE THREE CONDUCTORS FOR
C      PHASE ONE
C      WRITE (6,15)

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ACR01660
ACR01670
ACR01680
ACR01690
ACR01700
ACR01710
ACR01720
ACR01730
ACR01740
ACR01750
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ACR01770
ACR01780
ACR01790
ACR01800
ACR01810
ACR01820
ACR01830
ACR01840
ACR01850
ACR01860
ACR01870
ACR01880
ACR01890
ACR01900
ACR01910
ACR01920
ACR01930
ACR01940
ACR01950
ACR01960
ACR01970
ACR01980
ACR01990
ACR02000
ACR02010
ACR02020
ACR02030
ACR02040
ACR02050
ACR02060
ACR02070
ACR02080
ACR02090
ACR02100
ACR02110
ACR02120
ACR02130
ACR02140
ACR02150
ACR02160
ACR02170
ACR02180
ACR02190
ACR02200

FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

15  FORMAT('0',5X,'VALUES OF MODAL CURRENTS IN EACH CONDUCTOR')
    F = 200.00
    CALL CONST (V,F,ALPHA)
    DO 94 I = 1,3
      IC2(I,1) = JC(I,1)/(2.00*SQRT(ALPHA(I)))
      WRITE (6,16) (I,IC2(I,1),I=1,3)
16  FORMAT(15X,'IC2I ('',I1,'',1) =',F10.3,2X,'MICROAMP')
    C
      F = 500.00
      CALL CONST (V,F,ALPHA)
      DO 95 I = 1,3
        IC5(I,1) = JC(I,1)/(2.00*SQRT(ALPHA(I)))
        WRITE (6,13) (I,IC5(I,1),I=1,3)
95  FORMAT(15X,'IC5I ('',I1,'',1) =',F10.3,2X,'MICROAMP')
    C
    C   TO DETERMINE THE PHASE CURRENTS IP(I,J)
    C   FOR FREQUENCY AT 200 KHZ
    C   WRITE (6,71)
71  FORMAT('0',5X,'VALUES OF MODAL CURRENTS (MICROA) AT 200 KHZ')
    K = 1
    CALL IPHASE (M,K,KK,KKK,IC2I,IC5I,IC22,IC52,IC23,IC53,IP)
    DO 96 I = 1,3
      DO 96 J = 1,3
        IP2I(I,J) = IP(I,J)
        WRITE (6,12) ((IP2I(I,J),J=1,3),I=1,3)
96  C
    C   FOR FREQUENCY AT 500 KHZ
    C   WRITE (6,72)
72  FORMAT('0',5X,'VALUES OF MODAL CURRENTS (MICROA) AT 500 KHZ')
    K = 2
    CALL IPHASE (M,K,KK,KKK,IC2I,IC5I,IC22,IC52,IC23,IC53,IP)
    DO 97 I = 1,3
      DO 97 J = 1,3
        IPSI(I,J) = IP(I,J)
        WRITE(6,12) ((IPSI(I,J),J=1,3),I=1,3)
97  C
    C   =====
    C   COMPUTATION FOR PHASE TWO ONLY
    C   =====
    C
    C   WRITE (6,14)
    C   DO 22 I = 1,3
    C   JC(I,1) = GM(I,2)*TAU(2)
    C   WRITE (6,99) (JC(I,1),I=1,3)
22  C
    C   TO DETERMINE MODAL CURRENTS IN THE THREE CONDUCTORS
    C   WRITE (6,15)
    C   F = 200.00
    C   CALL CONST (V,F,ALPHA)
    C   DO 23 I = 1,3
23  IC22(I,1) = JC(I,1)/(2.00*SQRT(ALPHA(I)))
    C   WRITE (6,24) (I,IC22(I,1),I=1,3)
24  FORMAT(15X,'IC22 ('',I1,'',1) =',F10.3,2X,'MICROAMP')
    C

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ACRO2210
 ACRO2220
 ACRO2230
 ACRO2240
 ACRO2250
 ACRO2260
 ACRO2270
 ACRO2280
 ACRO2290
 ACRO2300
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 ACRO2320
 ACRO2330
 ACRO2340
 ACRO2350
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 ACRO2380
 ACRO2390
 ACRO2400
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 ACRO2490
 ACRO2500
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 ACRO2580
 ACRO2590
 ACRO2600
 ACRO2610
 ACRO2620
 ACRO2630
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 ACRO2650
 ACRO2660
 ACRO2670
 ACRO2680
 ACRO2690
 ACRO2700
 ACRO2710
 ACRO2720
 ACRO2730
 ACRO2740
 ACRO2750

FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

      F = 500.00
      CALL CONST(V,F,ALPHA)
      DO 25 I = 1,3
25    IC52(I,1) = JC(I,1)/(2.00*SQRT(ALPHA(I)))
      WRITE (6,26) (I,IC52(I,1),I=1,3)
26    FORMAT(15X,'IC52 ('',I1,'',1) =',F10.3,2X,'MICROAMP')
C
C    TO DETERMINE THE PHASE CURRENTS
C    FOR FREQUENCY AT 200 KHZ
      WRITE (6,71)
      KK = 1
      CALL IPHASE (M,K,KK,KKK,IC21,IC511,IC22,IC52,IC23,IC53,IP)
      DO 32 I = 1,3
      DO 32 J = 1,3
32    IP22(I,J) = IP(I,J)
      WRITE (6,12) ((IP22(I,J),J=1,3),I=1,3)
C
C    FOR FREQUENCY AT 500 KHZ
      WRITE (6,72)
      KK = 2
      CALL IPHASE (M,K,KK,KKK,IC21,IC51,IC22,IC52,IC23,IC53,IP)
      DO 34 I = 1,3
      DO 34 J = 1,3
34    IPS2(I,J) = IP(I,J)
      WRITE (6,12) ((IPS2(I,J),J=1,3),I=1,3)
C
C
C    =====
C    COMPUTATION FOR PHASE THREE ONLY
C    =====
C
      WRITE (6,14)
      DO 101 I = 1,3
101    JC(I,1) = GM(I,3)*TAU(3)
      WRITE (6,99) (JC(I,1),I=1,3)
C
C    TO DETERMINE THE MODAL CURRENTS IN THE THREE CONDUCTORS
      WRITE (6,15)
      F = 200.00
      CALL CONST (V,F,ALPHA)
      DO 102 I = 1,3
102    IC23(I,1) = JC(I,1)/(2.00*SQRT(ALPHA(I)))
      WRITE (6,103) (I,IC23(I,1),I=1,3)
103    FORMAT(15X,'IC23 ('',I1,'',1) =',F10.3,2X,'MICROAMP')
C
      F = 500.00
      CALL CONST (V,F,ALPHA)
      DO 104 I = 1,3
104    IC53(I,1) = JC(I,1)/(2.00*SQRT(ALPHA(I)))
      WRITE (6,105) (I,IC53(I,1),I=1,3)
105    FORMAT(15X,'IC53 ('',I1,'',1) =',F10.3,2X,'MICROAMP')
C
C    TO DETERMINE THE THE PHASE CURRENT
C    FOR FREQUENCY AT 200 KHZ
      WRITE (6,71)

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ACR02760
 ACR02770
 ACR02780
 ACR02790
 ACR02800
 ACR02810
 ACR02820
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 ACR02850
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 ACR02960
 ACR02970
 ACR02980
 ACR02990
 ACR03000
 ACR03010
 ACR03020
 ACR03030
 ACR03040
 ACR03050
 ACR03060
 ACR03070
 ACR03080
 ACR03090
 ACR03100
 ACR03110
 ACR03120
 ACR03130
 ACR03140
 ACR03150
 ACR03160
 ACR03170
 ACR03180
 ACR03190
 ACR03200
 ACR03210
 ACR03220
 ACR03230
 ACR03240
 ACR03250
 ACR03260
 ACR03270
 ACR03280
 ACR03290
 ACR03300

FILE: ACRI FORTRAN 4 OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITY LAB

```

      KKK = 1
      CALL IPHASE (M,K,KK,KKK,IC21,IC51,IC22,IC52,IC23,IC53,IP)
      DO 106 I = 1,3
      DO 106 J = 1,3
106   IP23(I,J) = IP(I,J)
      WRITE (6,12) ((IP23(I,J),J=1,3),I=1,3)
C
C   FOR FREQUENCY AT 500 KHZ
      WRITE (6,72)
      KKK = 2
      CALL IPHASE (M,K,KK,KKK,IC21,IC51,IC22,IC52,IC23,IC53,IP)
      DO 107 I = 1,3
      DO 107 J = 1,3
107   IP53(I,J) = IP(I,J)
      WRITE (6,12) ((IP53(I,J),J=1,3),I=1,3)
C
C   GO TO 700
C
C   =====
C   PART (A) WILL COMPUTE THE RI NOISE LEVEL FROM THE AC TRANSMISSION
C   LINES ALONG THE LATERAL DISTANCE WITH THE RECEIVER ALTITUDE AT
C   GROUND LEVEL.
C   PART (B) WILL COMPUTE THE CRITICAL DISTANCES WHERE THE RATIO OF
C   DESIRED SIGNAL (FROM NDA)/UNDESIRE NOISE (RI) IS 15 DB WITH THE
C   RECEIVER ALTITUDES AT 500',1000' AND 1500'.
C   =====
C
C   PART (A)
700  CONTINUE
C   WITH KNOWN MODAL CURRENTS CALCULATED ABOVE THE RI NOISE AT
C   GROUND LEVEL COULD BE DETERMINED NOW
C   FOR FREQUENCY AT 200 KHZ AND 500 KHZ
      WRITE (6,62)
62   FORMAT('0',T17,'YLOC',T30,'XLOC',T44,'EN200',T59,'EN500')
C
      IALT = 0
      YLOC = FLOAT(IALT)*0.3049
      XF = 500.00
      XI = 0.0
      NP = 100
      XD = (XF-XI)/FLOAT(NP)
      XP = XI
      DO 77 I = 1,NP
      XP = XP + XD
      J = I+NP
      XLOC = XP*0.3049
C
      K=1
      CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)
      EA2 = FE
      K=2
      CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)
      EA5 = FE
C
      V(I) = FA2

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ACRO3310
 ACRO3320
 ACRO3330
 ACRO3340
 ACRO3350
 ACRO3360
 ACRO3370
 ACRO3380
 ACRO3390
 ACRO3400
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 ACRO3420
 ACRO3430
 ACRO3440
 ACRO3450
 ACRO3460
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FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITY LAPI

```

      X(I) = XP
      Y(I) = FAS
      X(J) = XP
C
      WRITE (6,78) IALT1,X(I),Y(I),Y(IJ)
78  FORMAT(10X,11R,3F15.3)
77  CONTINUE
      CALL MPLOT(X,Y,NP,?,XL,YL)
      GO TO 922
C
C
C      PART (R)
C      CONTINUE
900  LFT HEIGHT OF ANTENNA RE 40'.    K=1 IF FREQUENCY IS 200 KHZ AND
C      K=2 IF FREQUENCY IS 500 KHZ
C      WRITE (6,550)
550  FORMAT('0',T11,'00(NH)',T24,'010',T40,'0(500)',T56,'0(1000)',
2      T72,'0(1500)')
C
      K = 2
      H1 = 40.00*0.3049
      XF = 20.00
      XI = 0.00
      NP = 20
      DX = (XF-XI)/FLOAT(NP)
      XP = XI
      DO 400 J = 1,NP
      XP = XP+DX
      J = J+NP
      L = J+NP
      N = L+NP
C
      GO TO 525
C
      FOR RECEIVER ALTITUDE AT GROUND LEVEL (H2=0.0')
      DO 500 INC = 1,10000
      CALL SIGNAL (INC,K,XP,H1,H2,P1,EPST,SIGMA,ERP,C,FFS)
      SIG1 = FFS
      YLOC = H2
      XLNC = FLOAT(INC)*0.3049
      CALL NOISE (K,XLNC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)
      RINI = EE
      DELTA1 = SIG1-RINI
      IF (DELTA1.GE.-15.00) GO TO 600
500  CONTINUE
600  DIST1 = FLOAT(INC)
C
C
505  CONTINUE
C
      FOR RECEIVER ALTITUDE AT 500' (H2=500.0')
      H2 = 500.00*0.3049
      DO 501 INC = 1,10000,10
      CALL SIGNAL (INC,K,XP,H1,H2,P1,EPST,SIGMA,ERP,C,FFS)
      SIG2 = FFS
      YLOC = H2
      XLNC = FLOAT(INC)*0.3049
      CALL NOISE (K,XLNC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)

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 ACRO3990
 ACRO4000
 ACRO4010
 ACRO4020
 ACRO4030
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 ACRO4090
 ACRO4100
 ACRO4110
 ACRO4120
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 ACRO4190
 ACRO4200
 ACRO4210
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 ACRO4230
 ACRO4240
 ACRO4250
 ACRO4260
 ACRO4270
 ACRO4280
 ACRO4290
 ACRO4300
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 ACRO4320
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 ACRO4370
 ACRO4380
 ACRO4390
 ACRO4400

FILE: ACPI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

      RIN2 = EE
      DELTA2 = SIG2-RIN2
      IF(DELTA2.GE.15.00) GO TO601
501  CONTINUE
601  DIST2 = FLOAT(INC)
      C
      C   FOR RECEIVER ALTITUDE AT 1000' (H2=1000')
      H2 = 1000.00*0.3049
      DO 502 INC = 1,10000,10
      CALL SIGNAL (INC,K,XP,H1,H2,PI,EPSI,SIGMA,ERP,C,FFS)
      SIG3 = FFS
      YLOC = H2
      XLOC = FLOAT(INC)*0.3049
      CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)
      RIN3 = EE
      DELTA3 = SIG3-RIN3
      IF(DELTA3.GE.15.00) GO TO 602
502  CONTINUE
602  DIST3 = FLOAT(INC)
      C
      C   FOR RECEIVER ALTITUDE AT 1500' (H2=1500')
      H2 = 1500.00*0.3049
      DO 503 INC = 1,10000,10
      CALL SIGNAL (INC,K,XP,H1,H2,PI,EPSI,SIGMA,ERP,C,FFS)
      SIG4 = FFS
      YLOC = H2
      XLOC = FLOAT(INC)*0.3049
      CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)
      RIN4 = EE
      DELTA4 = SIG4-RIN4
      IF(DELTA4.GE.15.00) GO TO 603
503  CONTINUE
603  DIST4 = FLOAT(INC)
      C
      Y(I) = XP
      X(I) = DIST1
      Y(J) = XP
      X(J) = DIST2
      Y(L) = XP
      X(L) = DIST3
      Y(N) = XP
      X(N) = DIST4
      C
      C
      WRITE (6,401) Y(I),X(J),X(L),X(N),SIG2,RIN2,SIG3,RIN3
401  FORMAT(8F8.1)
400  CONTINUE
      C   CALL MPLOT (X,Y,NP,4,XL,YL)
      WRITE (6,199) K,ERP
199  FORMAT(5X,I5,F10.3)
      C
      GO TO 2000
      C
      C
900  CONTINUE

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ACR04410
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 ACR04600
 ACR04610
 ACR04620
 ACR04630
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 ACR04680
 ACR04690
 ACR04700
 ACR04710
 ACR04720
 ACR04730
 ACR04740
 ACR04750
 ACR04760
 ACR04770
 ACR04780
 ACR04790
 ACR04800
 ACR04810
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 ACR04900
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 ACR04950

FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

C      THIS PART WILL COMPUTE THE RI NOISE AT ANY POINT OF
C      OBSERVATION.
C      K = 2
C      KK = 2
C      DO 1000 I = 2,400,KK
C      IF(1.GE.100) KK = 25
C      XLNC = FLOAT(I)*0.3049
C      H2 = 000.00*0.3049
C      YLOC = H2
C      CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)
C      E0 = EE
C      H2 = 500.00*0.3049
C      YLOC = H2
C      CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)
C      E500 = EE
C      H2 = 1000.00*0.3049
C      YLOC = H2
C      CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)
C      E1000 = EE
C      YLOC = 1500.00*0.3049
C      CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)
C      E1500 = EE
C      WRITE (6,1200) I,E0,E500,E1000,E1500
1200  FORMAT (5X,15,4(F10.3))
1000  CONTINUE
2000  CONTINUE
      STOP
      END
C      SUBROUTINE INVERS (K,G,H,ZI)
C      DIMENSION G(30,30),Z(30,30),ZI(30,30),ZC(30,30),ZA(30,30)
C      REAL M(30,30)
C      DO 9 J = 1,3
C      DO 9 I = 1,3
C      IF(K.EQ.1) Z(I,J) = G(I,J)
C      IF(K.EQ.2) Z(I,J) = M(I,J)
C      CONTINUE
9
C
C      TO OBTAIN COFACTOR MATRIX (ZC)
C      ZC(1,1) = +(Z(2,2)*Z(3,3)-Z(3,2)*Z(2,3))
C      ZC(1,2) = -(Z(2,1)*Z(3,3)-Z(3,1)*Z(2,3))
C      ZC(1,3) = +(Z(2,1)*Z(3,2)-Z(3,1)*Z(2,2))
C      ZC(2,1) = -(Z(1,2)*Z(3,3)-Z(3,2)*Z(1,3))
C      ZC(2,2) = +(Z(1,1)*Z(3,3)-Z(3,1)*Z(1,3))
C      ZC(2,3) = -(Z(1,1)*Z(3,2)-Z(3,1)*Z(1,2))
C      ZC(3,1) = +(Z(1,2)*Z(2,3)-Z(2,2)*Z(1,3))
C      ZC(3,2) = -(Z(1,1)*Z(2,3)-Z(2,1)*Z(1,3))

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ACR04960
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 ACR05400
 ACR05410
 ACR05420
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 ACR05450
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 ACR05480
 ACR05490
 ACR05500

FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

C      ZC(3,3) = +(Z(1,1)*Z(2,2)-Z(2,1)*Z(1,2))
C      TO OBTAIN ADJOINT MATRIX (ZA)
C      DO 1 J = 1,3
C      DO 1 I = 1,3
1      ZA(I,J) = ZC(J,I)
C
C      TO DETERMINE THE VALUE OF DETERMINANT OF (Z)
C      DET = (Z(1,1)*Z(2,2)*Z(3,3)-Z(3,2)*Z(2,3))
2      - (Z(1,2)*Z(2,1)*Z(3,3)-Z(3,1)*Z(2,3))
3      + (Z(1,3)*Z(2,1)*Z(3,2)-Z(3,1)*Z(2,2))
C
C      TO OBTAIN INVERSE MATRIX OF (Z)
C      DO 2 J = 1,3
C      DO 2 I = 1,3
2      ZI(I,J) = ZA(I,J)/DET
      RETURN
      END
C
C      SUBROUTINE CONST (V,F,ALPHA)
C      ALPHAS DEPEND ON FREQUENCY IN MHZ AND GROUND RESISTIVITY IN
C      OHM.M. UNDER HEAVY RAIN CONDITION GROUND RESISTIVITY IS 75.0 O.M.
C      DIMENSION ALPHA (10),VLINE(10),BETA(30)
C      F = F/1.00E3
C      TO FIND THE VOLTAGE CLASS
C      VLINE(1) = 362.00
C      VLINE(2) = 550.00
C      VLINE(3) = 800.00
C      VLINE(4) = 1200.0
C      DO 1 I = 1,4
C      DELTA = VLINE(I) - V
C      IF (DELTA.GE.10.00) GO TO 2
1      CONTINUE
2      IF (I.EQ.1) GO TO 3
C      IF (I.EQ.2) GO TO 4
C      IF (I.EQ.3) GO TO 5
C      IF (I.EQ.4) GO TO 6
3      BETA(1) = 8.00E-6
C      BETA(2) = 60.00E-6
C      BETA(3) = 350.00E-6
C      GO TO 7
4      BETA(1) = 9.30E-6
C      BETA(2) = 70.00E-6
C      BETA(3) = 350.00E-6
C      GO TO 7
5      BETA(1) = 10.00E-6
C      BETA(2) = 70.00E-6
C      BETA(3) = 350.00E-6
C      GO TO 7
6      BETA(1) = 10.60E-6
C      BETA(2) = 84.00E-6
C      BETA(3) = 350.00E-6
C      GO TO 7
7      CONTINUE
C      DO 8 I = 1,3

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ACRO5510
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 ACRO5670
 ACRO5680
 ACRO5690
 ACRO5700
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 ACRO5980
 ACRO5990
 ACRO6000
 ACRO6010
 ACRO6020
 ACRO6030
 ACRO6040
 ACRO6050

FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LABO

```

8  ALPHA(I) = (F**C.8)*SORT(0.750)*BETA(I)
   WRITE (6,9)
9  FORMAT('0',10X,'VALUES OF ALPHAS')
   WRITE (6,10) (I,ALPHA(I),I=1,3)
10 FORMAT(10X,'ALPHA (' ,11,' ) =',G10.3)
   RETURN
   END
C
SUBROUTINE IPHASE (K,K,KK,KKK,IC21,IC51,IC22,IC52,IC23,IC53,IP)
REAL IC(20,20),M(30,30),IC21(20,20),IC51(20,20),IP(20,20)
REAL IC22(20,20),IC52(20,20)
REAL IC23(20,20),IC53(20,20)
REAL M(30,30)
DO 1 J = 1,3
DO 1 I = 1,3
1  M(I,J) = M(J,I)
DO 2 I = 1,3
IF(K.EQ.1) IC(I,1) = IC21(I,1)
IF(K.EQ.2) IC(I,1) = IC51(I,1)
IF(KK.EQ.1) IC(I,1) = IC22(I,1)
IF(KK.EQ.2) IC(I,1) = IC52(I,1)
IF(KKK.EQ.1) IC(I,1) = IC23(I,1)
IF(KKK.EQ.2) IC(I,1) = IC53(I,1)
2  CONTINUE
DO 3 I = 1,3
DO 3 J = 1,3
3  IP(I,J) = M(I,J)*IC(I,1)
   RETURN
   END
C
SUBROUTINE NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,
2  FE)
REAL IP1(20,20),IP2(20,20),IP3(20,20)
REAL IP21(30,30),IP51(30,30)
REAL IP22(20,20),IP52(20,20),IP23(20,20),IP53(20,20)
DIMENSION FF(30,30),F1(20,20),E2(20,20),F3(20,20)
DO 1 J = 1,3
DO 1 I = 1,3
IF(K.EQ.1) GO TO 10
IF(K.EQ.2) GO TO 11
10 IP1(I,J) = IP21(I,J)
   IP2(I,J) = IP22(I,J)
   IP3(I,J) = IP23(I,J)
   GO TO 1
11 IP1(I,J) = IP51(I,J)
   IP2(I,J) = IP52(I,J)
   IP3(I,J) = IP53(I,J)
1  CONTINUE
C
X = XLOC
Y = X*D
Z = X-D
W = YLOC+H
U = YLOC-H
C

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ACR06060
ACR06070
ACR06080
ACR06090
ACR06100
ACR06110
ACR06120
ACR06130
ACR06140
ACR06150
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ACR06170
ACR06180
ACR06190
ACR06200
ACR06210
ACR06220
ACR06230
ACR06240
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ACR06310
ACR06320
ACR06330
ACR06340
ACR06350
ACR06360
ACR06370
ACR06380
ACR06390
ACR06400
ACR06410
ACR06420
ACR06430
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ACR06460
ACR06470
ACR06480
ACR06490
ACR06500
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ACR06540
ACR06550
ACR06560
ACR06570
ACR06580
ACR06590
ACR06600

FILE: ACRI FORTRAN OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

      FY1 = 60.00*(IW/(Y*Y + W*W)) - (U/(Y*Y + U*U))
      FX1 = 60.00*Y*((1.00/(Y*Y + U*U)) - (1.00/(Y*Y + W*W)))
      FF(1,1) = SQRT(FY1*FY1 + FX1*FX1)
C
      FY2 = 60.00*(IW/(X*X + W*W)) - (U/(X*X + U*U))
      FX2 = 60.00*X*((1.00/(X*X + U*U)) - (1.00/(X*X + W*W)))
      FF(2,1) = SQRT(FY2*FY2 + FX2*FX2)
C
      FY3 = 60.00*(IW/(Z*Z + W*W)) - (U/(Z*Z + U*U))
      FX3 = 60.00*Z*((1.00/(Z*Z + U*U)) - (1.00/(Z*Z + W*W)))
      FF(3,1) = SQRT(FY3*FY3 + FX3*FX3)
C
C      TO MULTIPLY THE MODAL PHASE CURRENTS WITH THE FIELD FACTORS
C      FF(I,J) TO OBTAIN THE PI NOISE LEVEL IN MICROV/M
C      DO 2 I = 1,3
      J = 1
      E1(I,J) = 0.0
      DO 2 INDEX = 1,3
2      E1(I,J) = E1(I,J) + IPI(I,INDEX)*FF(INDEX,J)
C
      DO 3 I = 1,3
      J = 1
      E2(I,J) = 0.0
      DO 3 INDEX = 1,3
3      E2(I,J) = E2(I,J) + IP2(I,INDEX)*FF(INDEX,J)
C
      DO 4 I = 1,3
      J = 1
      E3(I,J) = 0.0
      DO 4 INDEX = 1,3
4      E3(I,J) = E3(I,J) + IP3(I,INDEX)*FF(INDEX,J)
C
      EE1 = 0.0
      J = 1
      DO 5 I = 1,3
5      EE1 = EE1 + SQRT(E1(I,J)*E1(I,J))
C
      EE2 = 0.0
      J = 1
      DO 6 I = 1,3
6      EE2 = EE2 + SQRT(E2(I,J)*E2(I,J))
C
      EE3 = 0.0
      J = 1
      DO 7 I = 1,3
7      EE3 = EE3 + SQRT(E3(I,J)*E3(I,J))
C
      ETOT = SQRT(EE1*EE1 + EE2*EE2 + EE3*EE3)
      EF = 20.00*ALOG10(ETOT)
      RETURN
      END
C
      SUBROUTINE SIGNAL (INC,K,XP,H1,H2,PI,EPSI,SIGMA,ERP,C,EFS)
      REAL LAMBDA
      COMPLEX ETA,DELTA,Q,RHO,ERF,ERFC,T,TT,A

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ACR06610
ACR06620
ACR06630
ACR06640
ACR06650
ACR06660
ACR06670
ACR06680
ACR06690
ACR06700
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ACR06720
ACR06730
ACR06740
ACR06750
ACR06760
ACR06770
ACR06780
ACR06790
ACR06800
ACR06810
ACR06820
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ACR06870
ACR06880
ACR06890
ACR06900
ACR06910
ACR06920
ACR06930
ACR06940
ACR06950
ACR06960
ACR06970
ACR06980
ACR06990
ACR07000
ACR07010
ACR07020
ACR07030
ACR07040
ACR07050
ACR07060
ACR07070
ACR07080
ACR07090
ACR07100
ACR07110
ACR07120
ACR07130
ACR07140
ACR07150

FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LABO

```

COMPLEX Z,Z1,Z2,Z3,Z4
IF(K.EQ.1) F = 200.00
IF(K.EQ.2) F = 500.00
C
EE = -1.800E7*SIGMA/F
ETA = CMPLX(EPSI,EF)
DELTA = CSQRT(ETA-1.00)/ETA
LAMRDA = C/(F*1.00F3)
CK = 2.00*PI/LAMRDA
C
R = XP*1852.00 + FLOAT(INC)*0.3049
DD = SQRT(R*R + (H1-H2)**2)
RR = SQRT(PI*CK*DD/2.00)
OO = PI/4.00
Q = CMPLX(10.00,QQ)
RHO = CEXP(Q)*RR
C
Z = CEXP(Q)*SQRT(CK*DD/2.00)*DELTA*(1.00+((H1+H2)/(DELTA*DD)))
Z1 = Z
Z2 = (Z**3)/(13.0*1.0)
Z3 = (Z**5)/(15.0*2.0*1.0)
Z4 = (Z**7)/(17.0*3.0*2.0*1.0)
ERF = (Z1-Z2+Z3-Z4)*(2.00/SQRT(PI))
ERFC = 1.000-ERF
C
T = Z*Z
TT = CEXP(T)
A = 1.00-(RHO*DELTA*TT*ERFC)
ES = (9.487*SQRT(ERF)/(R))*CABS(A)*1.00F6
EFS = 20.00*ALOG10(ES)
RETURN
END

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ACR07160
ACR07170
ACR07180
ACR07190
ACR07200
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ACR07310
ACR07320
ACR07330
ACR07340
ACR07350
ACR07360
ACR07370
ACR07380
ACR07390
ACR07400
ACR07410
ACR07420
ACR07430
ACR07440
ACR07450
ACR07460
ACR07470

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C      TO COMPUTE THE SIGNAL STRENGTH OF AN NDR TRANSMITTER
C      GROUND CONDUCTIVITY IS 10 MMHO/M
C      RELATIVE PERMITTIVITY IS 10
C      EFFECTIVE RADIATED POWER IS 1 KW
C
C      DIMENSION Y(200),X(200),YI(12),XI(12)
C      DATA YI/'S','I','G','N','A','L',' ',' ','I','N',' ',' ','N','B'/'
C      DATA XI/'D','I','S','T',' ',' ',' ','I','N',' ',' ',' ','N','M'/'
C      COMPLEX FTA,DEL,Q,PD,Z,ERF,ERFC,T,TT,A
C      COMPLEX Z1,Z2,Z3,Z4
C
C      DATA PI,E,SIG,P,C/3.1416,10.0,0.010,10.00,3.0E8/'
C
C      WRITE (6,20)
C      FORMAT('I',T20,'DIST(NM)',T35,'FSDR(200)',T50,'ESDR(500)')
C
C      XF = 100.0
C      XI = 0.0
C      NP = 100.0
C      DX = (XF-XI)/FLOAT(NP)
C      Q = XI
C      DO 1 I = 1,NP
C      Q = Q+DX
C      J = I + 100
C      H1 = 40.0*0.3049
C      H = 0000.0
C      H2 = H*0.3049
C
C      FOR ERF2 OF 200 KHZ
C
C      F = 200.0
C      FE = -1.8E7*SIG/F
C      FTA = CMPLX(E,FE)
C
C      DEL = CSQRT(ETA-1.0)/FTA
C
C      WL = C/(F*1.0E3)
C      CK = 2.0*PI/WL
C      DD = SQRT((1*1R52.0)**2 + (H1-H2)**2)
C      PR = SQRT(PI*CK*DD/2.0)
C      Q0 = PI/4.0
C      Q = CMPLX(0.0,Q0)
C      PD = CEXP(Q)*RR
C
C      Z = CEXP(Q)*SQRT(CK*DD/2.0)*DEL*(1.0+((H1+H2)/(DEL*DD)))
C
C      TO COMPUTE THE ERF(Z)
C
C      Z1 = Z
C      Z2 = (Z**3)/(3.0*1.0)
C      Z3 = (Z**5)/(5.0*2.0*1.0)
C      Z4 = (Z**7)/(7.0*3.0*2.0*1.0)
C
C      ERF = (Z1-Z2+Z3-Z4)*(2.0/SQRT(PI))

```


FILE: DCRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

C      TO COMPUTE THE RI NOISE OF THE DC-LINE WITH THE POINT
C      OF OBSERVANCE AT ANY LOCATION.
C
C      CONSIDER ONLY THE POSITIVE POLE OF THE RI-POLAR AS
C      THE NEGATIVE POLE GIVES A NEGLIGIBLE RI LEVEL.
C
C      DIMENSION Y(200),X(200),YL(12),XL(12)
C      DATA YL/' ','R','I',' ',' ','L','E','V','E','L',' ',' ','D','I','S'/
C      DATA XL/'D','I','S','T',' ',' ','I','N',' ',' ','F','E','E','T'/
C
C      DATA PI,V,F/3.1416,600.0,200.0/
C      DATA NSUR,RAD,R,H,S/4,1.525,45.7,49.85,36.73/
C
C      ENDR1(E1) = E1
C      ENDR2(E2) = E2
C      ENDR3(E3) = E3
C      ENDR4(E4) = E4
C
C      TO DETERMINE THE MAXIMUM SURFACE GRADIENT.
C
C      R = R/(2.0*SIN(PI/FLOAT(NSUR)))
C      A = 1.0/FLOAT(NSUR)
C      N = NSUR-1
C      P = (FLOAT(NSUR)*RAD*(R**N))**A
C      Q = SQRT(((2.0*H/S)**2) + 1.0)
C      GG = 2.0*H*0.3049*100.0/(P*Q)
C      G = (1.0 + (FLOAT(N)*RAD/R))/(FLOAT(NSUR)*RAD*A*LOG(GG))
C
C      GMAX = G*V
C
C      WRITE (6,1) F,V,NSUR,RAD,R,H,S,G,GMAX
C      1  FORMAT('1',20X,'FREQ(KHZ)=' ,F10.3//21X,'VOLTAGE(+E-KV)=' ,
C      6    F10.3//21X,'NSUR=' ,I4//21X,'RADIUS OF SUR (CM)=' ,
C      6    F10.4//21X,'R (CM)=' ,F10.3//21X,'AVE HEIGHT (FT)=' ,
C      6    F10.3//21X,'POLE-POLE (FT)=' ,F10.3//21X,
C      6    'G (KV/CM/KV)=' ,F10.4//21X,'GMAX (KV/CM)=' ,
C      6    F10.4//)
C
C      TO COMPUTE THE RI AT GROUND LEVEL AND FROM THERE TO
C      DETERMINE THE TOTAL CURRENT IN THE CONDUCTOR. THEN
C      USE THE SUBROUTINE HEIGHT TO COMPUTE THE RI AT ANY LOCATION.
C
C      WRITE (6,4)
C      4  FORMAT('11','DIST(FT)',T24,'HP(0.0FT)',T36,'HP(250FT)',
C      6    T49,'HP(500FT)',T60,'HP(1000FT)')/
C
C      XF = 500.0
C      XI = 0.0
C      NP = 50
C      NX = (XF-XI)/FLOAT(NP)
C      D = XI
C      DO 2 I = 1,NP
C      D = D + NX

```

FILE: NCRI FORTYRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

      J = I + 50
      K = J + 50
      L = K + 50
C
C
      GPAT = GNAT/14.00
      DRAD = SQRT(H*M*D*D)*0.3049
C
      E = 214.0*ALOG10(GRAT) - 278.0*ALOG10(GRAT)*ALOG10(GRAT)
      2 + 40.0*ALOG10(RAD) + 27.0*ALOG10(834.0/F)
      3 + 40.0*ALOG10(30.5/DRAD)
C
C      TO COMPUTE THE RI NOISE AT DIFFERENT HEIGHT ABOVE GROUND
C      AT THE HEIGHT OF 0 FT.
      HP = 0.0
      CALL HEIGHT (E,H,HP,D,PI,EH)
      E1 = EH
C
C      AT THE HEIGHT OF 500 FT.
      HP = 250.0
      CALL HEIGHT (E,H,HP,D,PI,EH)
      E2 = EH
C
C      AT THE HEIGHT OF 1000 FT.
      HP = 500.0
      CALL HEIGHT (E,H,HP,D,PI,EH)
      E3 = EH
C
C      AT THE HEIGHT OF 5000 FT.
      HP = 1000.0
      CALL HEIGHT (E,H,HP,D,PI,EH)
      E4 = EH
C
C
      V(I) = ENDR1(E1)
      X(I) = D
      V(J) = ENDR2(E2)
      X(J) = D
      V(K) = ENDR3(E3)
      X(K) = D
      V(L) = ENDR4(E4)
      X(L) = D
C
C
      WRITE (6,3) X(I),V(I),V(J),V(K),V(L)
      3 FORMAT(5X,5F12.3)
      2 CONTINUE
      CALL M4PLOT (X,Y,50,4,XL,YL)
      STOP
      END
C
C      TO PUT IN SUBROUTINE HEIGHT
C
C      SUBROUTINE HEIGHT (E,H,HP,D,PI,EH)

```

```

DCR00560
DCR00570
DCR00580
DCR00590
DCR00600
DCR00610
DCR00620
DCR00630
DCR00640
DCR00650
DCR00660
DCR00670
DCR00680
DCR00690
DCR00700
DCR00710
DCR00720
DCR00730
DCR00740
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DCR00770
DCR00780
DCR00790
DCR00800
DCR00810
DCR00820
DCR00830
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DCR00850
DCR00860
DCR00870
DCR00880
DCR00890
DCR00900
DCR00910
DCR00920
DCR00930
DCR00940
DCR00950
DCR00960
DCR00970
DCR00980
DCR00990
DCR01000
DCR01010
DCR01020
DCR01030
DCR01040
DCR01050
DCR01060
DCR01070
DCR01080
DCR01090
DCR01100

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FILE: DCRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

C	E IS IN DB/MICV/M	DCR01110
C	EE IS IN MICV/M	DCR01120
C		DCR01130
	RAT = E/20.0	DCR01140
	FF = 10.0**RAT	DCR01150
C		DCR01160
C	TO GET CURRENT.	DCR01170
C	CURR = FF*((H*0.3049)**2 + (D*0.3049)**2)/(60.0*2.0*	DCR01180
	6 H*0.3049)	DCR01190
C		DCR01200
C	NOW USE CURRENT TO COMPUTE H-FIELD AT ANY POINT.	DCR01210
C		DCR01220
	P = (HP-H)*0.3049	DCR01230
	Q = (HP-H)*0.3049	DCR01240
	DD = D*0.3049	DCR01250
C		DCR01260
	HX = (CURR/(2.0*PI))*((P/(DD*DD + P*P)) - (Q/(DD*DD + Q*Q)))	DCR01270
	HY = (CURR*DD/(2.0*PI))*((1.0/(DD*DD + Q*Q)) - (1.0/	DCR01280
	6 (DD*DD + P*P)))	DCR01290
C		DCR01300
	FX = 120.0*PI*HX	DCR01310
	EY = 120.0*PI*HY	DCR01320
	EHP = SQRT(FX*FX + EY*EY)	DCR01330
	EH = 20.0*ALOG10(EHP)	DCR01340
	RETURN	DCR01350
	END	DCR01360

FILE: RJPICH FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITY LAB

```

      IMPLICIT REAL*8(A-H,O-Z,S)
      REAL*4 XM,XAR(100),YAR(100),XARL(12),YARL(12)
      COMPLEX*16 EP2,EP3,ETA,GAM,Y11,Z11,Z5
      COMPLEX*16 FUX,FUY,FUZ
      COMPLEX*16 FPPS,FPTS,FTPS,FTTS,FX,FY,E7,UPLD
      COMPLEX*16 C(4095),CJ(90),EP(90),ET(90),FPP(90),ETT(90)
      DIMENSION I1(90),I2(90),I3(90),JA(90),JB(90)
      COMPLEX*16 CGD(99),SGD(99),CG(198),VG(198),ZLD(198)
      DIMENSION D(99),IA(99),IB(99),ISC(99),ND(99,4),ND(99)
      DIMENSION X(110),Y(110),Z(110)
      DATA PI,TP/3.14159265358979,6.28318530717958/
      DATA EO,UO/R.454E-12,1.2566E-6/

C
C   FOR THE PLOT
      DATA XARL/'D','I','S','T',' ',' ',' ',' ','N',' ',' ',' ','F','T'/
      DATA YARL/'M','A','C',' ',' ',' ',' ','N',' ',' ',' ','R',' ',' '/

C
2   FORMAT(1X,8F10.4)
3   FORMAT(1X,4F10.4/)
4   FORMAT(1X,115,8F10.4)
5   FORMAT(1H0)
6   FORMAT(1X,6F10.4/)
7   FORMAT(9F10.5)
8   FORMAT(1X,114,13I5)
9   FORMAT(3X,'MAX = ',15,3X,'MIN = ',15,3X,'N = ',15)
10  FORMAT(1X,215,2F10.2)
11  FORMAT(3F15.5)
      ICJ=90
      JNM=99
      DO 15 J=1,INM
15  ISC(J)=0
      READ(5,7)RM,EP2,SIG2,TD2
      WRITE(6,2)RM,ER2,SIG2,TD2
      READ(5,7)AM,CM,ER3,SIG3,TD3
      WRITE(6,2)AM,CM,FR3,SIG3,TD3
      READ(5,9)TRISC,IGAIN,INEAR,ISCAT,IWR,NGEN,NM,NP
      WRITE(6,8)TRISC,IGAIN,INEAR,ISCAT,IWR,NGEN,NM,NP
      READ(5,7)FMC,PHA,THA,PHI,THI,PHS,THS
      WRITE(6,2)FMC,PHA,THA,PHI,THI,PHS,THS
      DO 22 J=1,NM
      READ(5,9)IA(J),IB(J)
22  WRITE(6,9)J,IA(J),IB(J)
      DO 40 I=1,NP
      READ(5,11)X(I),Y(I),Z(I)
40  WRITE(6,4)I,X(I),Y(I),Z(I)
      READ(5,11)XP,YP,ZP
      XXP=XP
      YYP=YP
      ZZP=ZP
      FH7=FMC*1.E6
      OMEGA=1P*FMZ
      IF(SIG2.LT.0.)EP2=ER2*EO*DCMPLX(1.0D00,-TD2)
      IF(TD2.LT.0.)EP2=DCMPLX(FR2*EO,-SIG2/OMEGA)
      IF(SIG3.LT.0.)EP3=ER3*EO*DCMPLX(1.0D00,-TD3)
      IF(TD3.LT.0.)EP3=DCMPLX(FR3*EO,-SIG3/OMEGA)

```

```

RJL00010
RJL00020
RJL00030
RJL00040
RJL00050
RJL00060
RJL00070
RJL00080
RJL00090
RJL00100
RJL00110
RJL00120
RJL00130
RJL00140
RJL00150
RJL00160
RJL00170
RJL00180
RJL00190
RJL00200
RJL00210
RJL00220
RJL00230
RJL00240
RJL00250
RJL00260
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RJL00280
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RJL00300
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RJL00380
RJL00390
RJL00400
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RJL00420
RJL00430
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RJL00450
RJL00460
RJL00470
RJL00480
RJL00490
RJL00500
RJL00510
RJL00520
RJL00530
RJL00540
RJL00550

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FILE: RJLRICH FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

      FTA=CDSORT(U0/FP3)
      GAM=OMEGA*CDSQR(1-U0*FP3)
      CALL PLSORT(IA,IR,I1,I2,I3,JA,JR,MD,ND,NM,NP,N,MAX,MIN,ICJ,INM)
      WRITE(6,5)
      WRITE(6,9)MAX,MIN,N
      WRITE(6,5)
      IF(MAX.GT.4 .OR. MIN.LT.1 .OR. N.GT.ICJ)GO TO 800
      INT=4
      I12=1
      DO 60 J=1,NM
      VG(J)=(.0,.0)
      ZLD(J)=(.0,.0)
      JJ=J+NM
      VG(JJ)=(.0,.0)
60    ZLD(JJ)=(.0,.0)
      IF(INGEN.GT.0)VG(INGEN)=(1,.0)
      CALL SGANT(IA,IR,INM,INT,ISC,I1,I2,I3,JA,JR,MD,N,ND,NM,NP
      Z,AM,AN,C,CGD,CMH,D,FP2,EP3,ETA,FHZ,GAM,SGD,X,Y,Z,ZLD,ZS)
      IF(N.LE.0)GO TO 800
      IF(INGEN.LE.0)GO TO 400
      CALL GANT1(IA,IB,INM,IWR,I1,I2,I3,I12,JA,JR,MD,N,ND,NM,AM
      Z,C,CJ,CG,CMH,D,EFF,GAM,GG,CGD,SGD,VG,Y11,Z11,ZLD,ZS)
      GO TO 867
963  DO 100 I=1,N
      ID=(I-1)*N-(I*I-1)/2
      DO 100 J=1,N
      IJ=ID+J
      100 WRITE(6,101),J,C(IJ)
867  CONTINUE
      WRITE(6,5)
      WRITE(6,3)EFF,GG,Z11
200  IF(INEAR.LE.0)GO TO 300
      C      LOOP TO CALCULATE NEAR ZONE PATTERN
      C      INPUT DIMENSIONS IN FEET
      C      ZP IS ELEVATION ABOVE GROUND
      C      XXP IS CLOSEST DISTANCE FROM TRANSMITTER
      C      YYP IS FARTHEST DISTANCE
      C
      NPTSRL=ZP
      XMINRL=XXP
      XMAXRL=YYP
      WRITE (8,345) NPTSRL, XMINRL, XMAXRL
345  FORMAT (15,7F15.5)
      C
      C      FOR VARIOUS POINTS OF X,Y,Z.
      C
      C      TO COMPUTE VALUES AT DIFFERENT ALTITUDES
      DO 999 IZHT = 1,3
      ZP = 500.0
      IF(IZHT.EQ.2) ZP = 1000.00
      IF(IZHT.EQ.3) ZP = 1500.00
      C
      C      GO TO 94
      C
999  CONTINUE

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RJL00560
 RJL00570
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 RJL00590
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 RJL01080
 RJL01090
 RJL01100

RJL0111C
RJL0111Z
RJL01130
RJL01140
RJL01150
RJL01160
RJL01170
RJL01190
RJL01199
RJL01200
RJL01210
RJL01220
RJL01230
RJL01240
RJL01250
RJL01260
RJL01279
RJL01280
RJL01290
RJL01309
RJL01310
RJL01320
RJL01330
RJL01340
RJL01350
RJL01360
RJL01370
RJL01399
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RJL01400
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RJL01480
RJL01490
RJL01500
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RJL01530
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RJL01550
RJL01560
RJL01570
RJL01580
RJL01590
RJL01600
RJL01610
RJL01620
RJL01630
RJL01640
RJL01650

FILE: RJLRICH FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LAB

```

      R1 = -13324.09
      Y1 = GRAD*X1 + R1
      X1 = X1/3.281
      Y1 = Y1/3.281
      Z1 = 5.0/3.281
      GO TO 99
C
93  CONTINUE
C
C  POINTS ALONG THE ACCESS ROAD WITH RESPECT TO THE CMH
C  TRANSMITTER
C
      X1 = 70715.0
      XF = 71215.0
      NP = 200
      NNP = 201
      DX = (XF-X1)/FLOAT(NP)
      DD = X1
      DO 84 I = 1, NNP
      XM = DD + FLOAT(I-1)*DX
      GRAD = -0.655
      BB = 46475.83
      Y1 = GRAD*XM + BB
      X1 = XM/3.281
      Y1 = Y1/3.281
      Z1 = 5.0/3.281
      GO TO 99
C
99  CONTINUE
C
      CALL GNFLO(I1,I2,INM,I1,I2,I3,MO,N,NO,NM,AM,CGO,SGO,ETA,GAM
      2,CJ,O,Y,Y,Z,XP,YP,ZP,EX,EY,FZ,FUX,EUY,EUZ)
      XP = XP*3.281
      YP = YP*3.281
      ZP = ZP*3.281
      WRITE(4,31)XP,YP,ZP
      FORMAT (3X,3F10.1)
31  WRITE(4,66)EX,EY,FZ,EUX,EUY,EUZ
      66  FORMAT (3(2X,2D12.4))
      RATIO1 = CDABS(EX)/CDABS(EZ)
      RATIO2 = CDABS(EUX)/CDABS(FUZ)
      RATIO3 = CDABS(EUY)/CDABS(EUZ)
      WRITE (6,32) RATIO1,RATIO2,RATIO3
32  FORMAT(15X,3F10.4)
C
C  FIELD STRENGTH ADJUSTED FOR UNI BEACON BY MULTIPLYING THE VALUE
C  OF ERP USED IN THE PROGRAM BY A FUDGE FACTOR....
C
C  FOR UNI BEACON ( ERP=0.7W ) THE FIELD STRENGTH AT 1 STATUTE
C  MILE IS 4933.3761 MICROW/M OR 73.9629 DB/1 MICV/M.
C
      FUDGE=4410.3273
      UFLD=(F7+EUX)*1000000.0
      F7=F7*1000000.
      EUZ=EUX*1000000.

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RJL01650
 RJL01670
 RJL01680
 RJL01690
 RJL01700
 RJL01710
 RJL01720
 RJL01730
 RJL01740
 RJL01750
 RJL01760
 RJL01770
 RJL01780
 RJL01790
 RJL01800
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 RJL02170
 RJL02180
 RJL02190
 RJL02200

FILE: JCH FORTRAN 4 OHIO UNIVERSITY ELECTROMAGNETIC COMPATIBILITIES LABO

	1=20,*DL0110(EU)MFC0DARS(E*U1)		RJL02210
	2=20,*DL0110(EU)MFC0DARS(E*U2)		RJL02220
	3=20,*DL0110(EU)MFC0DARS(E*U3)		RJL02230
	4=20,*DL0110(EU)MFC0DARS(E*U4)		RJL02240
	5=20,*DL0110(EU)MFC0DARS(E*U5)		RJL02250
	6=20,*DL0110(EU)MFC0DARS(E*U6)		RJL02260
	7=20,*DL0110(EU)MFC0DARS(E*U7)		RJL02270
	8=20,*DL0110(EU)MFC0DARS(E*U8)		RJL02280
	9=20,*DL0110(EU)MFC0DARS(E*U9)		RJL02290
	10=20,*DL0110(EU)MFC0DARS(E*U10)		RJL02300
	11=20,*DL0110(EU)MFC0DARS(E*U11)		RJL02310
	12=20,*DL0110(EU)MFC0DARS(E*U12)		RJL02320
	13=20,*DL0110(EU)MFC0DARS(E*U13)		RJL02330
	14=20,*DL0110(EU)MFC0DARS(E*U14)		RJL02340
	15=20,*DL0110(EU)MFC0DARS(E*U15)		RJL02350
	16=20,*DL0110(EU)MFC0DARS(E*U16)		RJL02360
	17=20,*DL0110(EU)MFC0DARS(E*U17)		RJL02370
	18=20,*DL0110(EU)MFC0DARS(E*U18)		RJL02380
	19=20,*DL0110(EU)MFC0DARS(E*U19)		RJL02390
	20=20,*DL0110(EU)MFC0DARS(E*U20)		RJL02400
	21=20,*DL0110(EU)MFC0DARS(E*U21)		RJL02410
	22=20,*DL0110(EU)MFC0DARS(E*U22)		RJL02420
	23=20,*DL0110(EU)MFC0DARS(E*U23)		RJL02430
	24=20,*DL0110(EU)MFC0DARS(E*U24)		RJL02440
	25=20,*DL0110(EU)MFC0DARS(E*U25)		RJL02450
	26=20,*DL0110(EU)MFC0DARS(E*U26)		RJL02460
	27=20,*DL0110(EU)MFC0DARS(E*U27)		RJL02470
	28=20,*DL0110(EU)MFC0DARS(E*U28)		RJL02480
	29=20,*DL0110(EU)MFC0DARS(E*U29)		RJL02490
	30=20,*DL0110(EU)MFC0DARS(E*U30)		RJL02500
	31=20,*DL0110(EU)MFC0DARS(E*U31)		RJL02510
	32=20,*DL0110(EU)MFC0DARS(E*U32)		RJL02520
	33=20,*DL0110(EU)MFC0DARS(E*U33)		RJL02530
	34=20,*DL0110(EU)MFC0DARS(E*U34)		RJL02540
	35=20,*DL0110(EU)MFC0DARS(E*U35)		RJL02550
	36=20,*DL0110(EU)MFC0DARS(E*U36)		RJL02560
	37=20,*DL0110(EU)MFC0DARS(E*U37)		RJL02570
	38=20,*DL0110(EU)MFC0DARS(E*U38)		RJL02580
	39=20,*DL0110(EU)MFC0DARS(E*U39)		RJL02590
	40=20,*DL0110(EU)MFC0DARS(E*U40)		RJL02600
	41=20,*DL0110(EU)MFC0DARS(E*U41)		RJL02610
	42=20,*DL0110(EU)MFC0DARS(E*U42)		RJL02620
	43=20,*DL0110(EU)MFC0DARS(E*U43)		RJL02630
	44=20,*DL0110(EU)MFC0DARS(E*U44)		RJL02640
	45=20,*DL0110(EU)MFC0DARS(E*U45)		RJL02650
	46=20,*DL0110(EU)MFC0DARS(E*U46)		RJL02660
	47=20,*DL0110(EU)MFC0DARS(E*U47)		RJL02670
	48=20,*DL0110(EU)MFC0DARS(E*U48)		RJL02680
	49=20,*DL0110(EU)MFC0DARS(E*U49)		RJL02690
	50=20,*DL0110(EU)MFC0DARS(E*U50)		RJL02700
	51=20,*DL0110(EU)MFC0DARS(E*U51)		RJL02710
	52=20,*DL0110(EU)MFC0DARS(E*U52)		RJL02720
	53=20,*DL0110(EU)MFC0DARS(E*U53)		RJL02730
	54=20,*DL0110(EU)MFC0DARS(E*U54)		RJL02740

[illegible]


```
C
      NR = -11374.09
      VM = GRAVITXM + RM
      XN = XM/3.281
      YP = YM/3.281
      ZP = ZM/3.281
      GC TO 94
C
93 C CONTINUE
C
C PRINTS ALONG THE ACCESS ROAD WITH RESPECT TO THE CHM
C TRANSMITTER
C
      V1 = 79715.0
      VF = 71715.0
      WP = 210
      WNP = 211
      IX = (XV-X1)/ELDAT(WP)
      QN = XI
      DE H6 J = 1,WNP
      XM = QN + ELDAT(1-1)*IX
      GRAD = -3.655
      RM = 46375.43
      YV = GRAVITXM + RM
      XP = XM/3.281
      YP = YM/3.281
      ZP = ZM/3.281
      GC TO 94
C
94 C CONTINUE
C
      CALL GNFID(I1,I2,I3,I4,I5,I6,I7,I8,I9,I0,N,NQ,NM,AM,CGD,SG),ETA,GAM
      ZC,I1,O,X,Y,Z,A,P,YP,ZP,FX,FY,FZ,EUX,EUY,EUZ
      VR = XPO3.281
      VP = YPO3.281
      ZP = ZPO3.281
      WRITE(6,11)XP,VP,ZH
11 FORMAT('X,X,3F10.1')
      KATH(6,46)FX,FY,EZ,FX,EUY,EUZ
A6 FORMAT('3(2X,20I2.4)')
      RATIO1 = CDAPS(FX)/CDAPS(EY)
      RATIO2 = CDAPS(EUX)/CDAPS(EUZY)
      RATIO3 = CDAPS(EUY)/CDAPS(EUZ)
      WRITE(6,32) RATIO1,RATIO2,RATIO3
32 FORMAT('154,3F10.4')
C
C FIELD STRENGTH ADJUSTED FOR UNI REACON BY MULTIPLYING THE VALUE
C OF ERP USED IN THE PROGRAM BY A FUDGE FACTOR....
C
      FOR UNI REACON ( ERPO=0.7W ) THE FIELD STRENGTH AT 1 STATUTE
      MILE IS 4933.3761 MICROW/M OR 73.8629 DB/I MIC/V.M.
C
      FUJFE=2004.0054
      JPLD=(1+FUJFE/100000.)
      IZ=CEP(100000.)
      FUJFE=IZ*100000.
```

KJL011660
KJL011670
KJL011680
KJL011690
KJL011700
KJL011710
KJL011720
KJL011730
KJL011740
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KJL011760
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KJL011790
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KJL020190
KJL020200

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WJL 027273
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R JL 027370
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WJL 027670
WJL 027680
WJL 027690
WJL 027700
WJL 027710
WJL 027720
WJL 027730
WJL 027740

Appendix C Acronyms

AC	Alternating Current
CMH	Designates particular NDB near Columbus, Ohio
dB	decibels
DC	Direct Current
DKG	Designates particular NDB near Columbus, Ohio
ERP	Effective Radiated Power
f	frequency, Hertz
KHz	Kilohertz
kV	Kilovolts
MHz	megahertz
NDB	Non-Directional Beacon
NM	nautical miles
RI	Radio Interference
s/n	signal to noise
vs	versus
ϵ_r	relative permittivity
σ	conductivity

